Journal of The Iron and Steel Institute

JANUARY 1956
Vol. 182 Part 1

Published Monthly
Editorial contents copyright by
The Iron and Steel Institute

EDITOR
K. Headlam-Morley

MANAGING EDITOR
E. R. Mort, B.SC., F.I.M.

TECHNICAL EDITOR
C. R. Harman, B.SC. (ENG.)

PRODUCTION EDITOR
H. F. Cleere, B.A.

ASSISTANT EDITOR
Elizabeth S. Fairhurst

EDITORIAL AND ADVERTISEMENT OFFICES

4 Grosvenor Gardens, London, S.W.1
SLOane 0061
Telegrams - - Irosamente, Sowest

SUBSCRIPTIONS

Members Free - Extra Copies Prices on application
Non-members - £10.0.0. per annum
Single Copies £1 each
Packing and postage 1s. per copy

NOTE

The Institute as a body is not responsible for statements made or opinions expressed in papers, articles, or discussions appearing in the Journal of The Iron and Steel Institute.

CONTENTS

PROCEEDINGS OF THE INSTITUTE

Report of Scunthorpe Meeting, 1955 1

THE IRON AND STEEL INSTITUTE

Soaking-Pit Practice at the Abbey Works of the Steel Company of Wales Ltd. *R. H. Slade* 3
The Effect of Temper-Rolling on the Strain-Ageing of Low-Carbon Steels *H. P. Tardif and C. S. Ball* 9
Sub-Structures in Ferrite *P. Samuel and A. G. Quarrell* 20
Reactions Involved in the First-Stage Graphitization of Iron–Carbon–Silicon Alloys *W. S. Owen and J. Wilcock* 38
Corrosion of Iron by Oxygen-Contaminated Sodium *G. W. Horsley* 43
The Structural Iron of the Parthenon *C. J. Livadefs* 49

CORRESPONDENCE ON PAPERS

Correspondence on the State of the Carbon in Austenite and Martensite as Revealed by the Eggertz Test 19

AFFILIATED LOCAL SOCIETIES

Some Factors Affecting Spring Design *W. R. Berry* 80

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The Traffic of Iron and Steelworks. Locomotive Operating *M. D. J. Brisby and J. H. Turnbull* 30
Interaction of Solutes in Liquid and Solid Solution in Iron *E. T. Turkdogan* 66
Silicon and Manganese Reactions in Ferromanganese Blast-Furnace Processes *E. T. Turkdogan* 74

NEWS 93 **ABSTRACTS** 97–120

THE IRON AND STEEL INSTITUTE, 6 GROSVENOR GARDENS, LONDON, S.W.1

AUXILIARY ROLLING MILL EQUIPMENT

WELLMAN

supplied the

80 inch Continuous Strip Pickle Line,

the largest of its type in Europe,

for the

Abbey Works of The Steel Company of Wales Ltd.

The Pickle Line will build up coils up to 20 tons in weight prior to cold rolling and has a capacity of 10,000 tons per 168 hour week.

Our products include the complete range of Mechanical Handling Machinery and Acid and Mechanical Processing Units for the production of steel strip.

THE WELLMAN SMITH OWEN ENGINEERING CORPN. LTD.

PARNELL HOUSE, WILTON ROAD, LONDON, S.W.1 WORKS: DARLASTON, SOUTH STAFFS.

HENRY M. MORGAN

HENRY MURDOCH MORGAN was born in 1912, and received his early education at Osborne High School and Thirsk Grammar School. On leaving school he continued his technical education at West Hartlepool Technical College.

After serving as a trainee engineer at the West Hartlepool works of the South Durham Steel and Iron Company, Ltd., Mr. Morgan joined the Cargo Fleet Iron Company, Ltd. (now incorporated in the South Durham group) in 1935 as Junior Assistant Works Engineer at the Cargo Fleet Iron Works, Middlesbrough. He became Senior Assistant Works Engineer two years later, and in 1945 was appointed Chief Works Engineer.

Mr. Morgan was elected a member of The Iron and Steel Institute in 1936, having joined the Cleveland Institution of Engineers the previous year. He was elected to the Council of the Cleveland Institution in 1951, and served as President for the session 1954–1955. As such he was an Honorary Member of the Council of The Iron and Steel Institute during his period of office. Mr. Morgan was elected a member of the Board of Governors of the Constantine Technical College, Middlesbrough, in 1945.

Henry M. Morgan

Honorary Member of Council 1954–1955

PROCEEDINGS OF

THE INSTITUTE

Reports of Council · Meetings · Notices

Special Meeting in Scunthorpe, 1955

A SPECIAL MEETING of The Iron and Steel Institute was held in Scunthorpe from Wednesday, 12th, to Friday, 14th October, 1955, by invitation of Lt.-Com. G. W. Wells, R.N. (RETD.), President, and the Council of the Lincolnshire Iron and Steel Institute. Three Technical Sessions were held at which six papers were presented and discussed. A full programme of visits to works and excursions to places of interest was arranged for Members and Ladies.

RECEPTION COMMITTEE

A Reception Committee consisting of Members of Council and Officers of The Lincolnshire Iron and Steel Institute was formed under the chairmanship of Lt.-Com. G. W. Wells, R.N. (RETD.), President, to make the arrangements in Scunthorpe. A Ladies' Committee was also formed under the chairmanship of Mrs. Wells.

The President and Council of The Iron and Steel Institute wish to express their sincere thanks to the President and Council of The Lincolnshire Iron and Steel Institute, to the Mayor and Corporation of Scunthorpe, to the Chairman and Members of the Ladies' Committee, to the directors of the works who kindly invited Members and Ladies to visit them, to the authors of papers, and to all others who collaborated in organizing the meeting.

Members and Ladies attending the meeting were accommodated in Scunthorpe, Lincoln, Doncaster, Barnby Moor, and other places in the district. About 450 Members and Ladies took part.

TECHNICAL SESSIONS

The Opening Session was held at the Drill Hall, Scunthorpe, on the morning of Wednesday, 12th October. In welcoming members of the Institute to Scunthorpe, Lt.-Com. **G. W. Wells** said: "It is very kind of you to have come so far to hear some papers written by the leading technicians in our Institute. We feel that it is a very great honour that The Iron and Steel Institute should pay us a visit. This is the first time in our history that we have had a special meeting of the Institute in Scunthorpe, although 23 years ago some members came over from Sheffield to spend half a day with us."

Lt.-Com. Wells went on to say that since the turn of the century the greatest advances in the fundamental techniques of iron and steel manufacture had been made in and about Scunthorpe. The first hot-metal tilting furnaces in Europe were operated in Frodingham in 1902, and the first mechanically charged blast-furnace at the same works in 1905. The first use of mixed blast-furnace and coke-oven gas was at Normanby in 1927. The general principles of the integration of iron and steelworks—particularly in connection with the use of a gasholder as a link between the ironworks and the steelworks—had been evolved in the Scunthorpe area, together with the thermal balance of iron and steelworks. In rolling-mill practice, Scunthorpe saw the first mechanical cooling bank and straightening plant and more recently flying shears applied to a large billet mill.

In ironmaking Scunthorpe had pioneered the adoption of bedding plant for ferrous ores, and also the introduction of carbon hearths. The most recent development was the large-scale introduction of the 100% self-fluxing sinter practice.

If this progress was to be maintained, the exchange of information and opinion was necessary, and Lt.-Com. Wells invited members to derive the fullest benefit from the technical papers to be presented, describing the Scunthorpe iron and steel industry.

He ended by saying "I thank you all once again for coming. I thank you, Mr. Lyttelton, for your original inception of the idea of coming to Scunthorpe, and I particularly thank you, Sir Charles, for accepting our invitation.

Sir **Charles Bruce-Gardner** (President of The Iron and Steel Institute) said in reply "On behalf of the Council of The Iron and Steel Institute, I thank Lt.-Com. Wells for the warm welcome he has extended to us. I also wish to thank him and the Council of the Lincolnshire Iron and Steel Institute for their invitation to hold a Special Meeting in Scunthorpe and for the most comprehensive arrangements they have made for the members."

The Lincolnshire Iron and Steel Institute was famed for the interest taken by its members in its proceedings and also in the proceedings of The Iron and Steel Institute. It was in September, 1933, that the Autumn Meeting of The Iron and Steel Institute, held in Sheffield, had visited the Frodingham Steel Company and John Lysaghts. The Chairman of the Reception Committee at that time was Mr. James Henderson, one of the famous names of the Scunthorpe industry, who had done so much in the early days to develop pig iron and steel making in the district.

Serious production in the Scunthorpe area began about 1870, when the Frodingham Iron Company expanded

their pig-iron production by building two more blast-furnaces. On the steelmaking side, it was interesting to look back to the end of the last century, when there were in the district only two 20-ton steel furnaces, with a total output of some 650 tons per week. At the beginning of this century the first tilting furnace was built. In 1911 there were three Talbot furnaces, the last one to be erected at that time being of about 150 tons capacity. It was about this time that John Lysaghts built their blast-furnaces and steelworks. Richard Thomas and Baldwins (at that time Richard Thomas) had been making iron for a long time, but it was not until later that they made steel.

In 1913 the production of iron ore was about 2,600,000 tons, and it had risen to 5½ million tons by 1954: the production of steel had risen to 2 million tons.

The visits to works and the technical papers stressed the importance of continual research and development, as evidenced by the tremendous developments all over the world. Magnificent new works, based on the latest technical knowledge, were being built; in Australia, for example, £60 million had been spent in the past five years. The recent visit of a Technical Mission to the Soviet Union should produce information about the new works and the technical development there.

" It is my duty to emphasize the continued necessity for technical improvement," Sir Charles concluded. " We have done a great deal since the war and I think that the British steel industry—and all industries in this country—can show a very fine record. I thank those who have so kindly prepared papers to be read, and I should like to convey our thanks to all those who have organized the visits to the works."

The Sir Robert Hadfield Medal for 1955 was then presented to Mr. T. F. Holmberg. The Hon. **R. G. Lyttelton** (Past President of The Iron and Steel Institute) said, in making the presentation, " The Sir Robert Hadfield Medal for 1955 was awarded to Mr. Tor Fjalar Holmberg, of Finland, by the Council during my year of office, in appreciation of his meritorious services in improving the technique of the production of iron and steel in Finland, and particularly at the works of his great firm, Oy Vuoksenniska Ab."

Some Members recently had the opportunity of seeing Fjalar Holmberg in action when they had appreciated his clear and enthusiastic descriptions and explanations, whether on the drawing board, in the works, or at his most up-to-date laboratories, as to what was being done in the way of original thought and ingenious design to solve the problems peculiar to steelmaking in Finland.

" The Council were confident that in awarding the Medal to Mr. Holmberg they were faithfully interpreting the wishes of that great man of steel, Sir Robert Hadfield. And how interested Sir Robert would have been in the fact that this is the first time this Medal has been given to someone outside this country, and how happy the decision to award it in Finland."

Mr. **Holmberg** said in reply, " I feel very honoured to receive this award, which I really have to share with my firm and my colleagues. Having read through the list of distinguished British technicians who have received the award I regard it as even more valuable. Please believe me when I say that I am very proud and happy to join such a company."

Two papers were then presented and discussed: one by Mr. G. D. Elliot, O.B.E., on " Developments in Ironmaking at Appleby-Frodingham " (*Journal*, 1955, vol. 181, Sept., pp. 1–16) and one by Mr. W. L. James on " The Expansion Scheme at John Lysaght's Scunthorpe Works, Ltd." (*Journal*, 1955, vol. 181, Sept., pp. 17–25).

On Thursday, 13th October, two simultaneous Technical Sessions were held. At St. Lawrence Church Hall, where Mr. Cedric Thomas was in the chair, the following papers were presented and discussed:

" Steelmaking at Redbourn " by S. R. Isaac (*Journal*, 1955, vol. 181, Sept., pp. 44–48).
" Organization for Maintenance " by J. L. Gaskell (*Journal*, 1955, vol. 181, Sept., pp. 71–83).

The other Session was in the Lecture Theatre, North Lindsey Technical College, with Mr. W. L. James in the chair. It was devoted to the presentation and discussion of the following papers:

" Underground Mining of the Frodingham Ironstone Bed at the Dragonby Mine, Scunthorpe " by C. Smith (*Journal*, 1955, vol. 181, Oct., pp. 150–158).
" Development of Chemical Methods for the Treatment of Low-Grade Ores at Appleby-Frodingham " by L. Reeve (*Journal*, 1955, vol. 181, Sept., pp. 26–40).

A report of the discussions at these Sessions will be published in the *Journal* in due course.

WORKS VISITS

Members were able to take part in one of the following six visits on the afternoons of Wednesday, 12th, and Thursday, 13th, and during the morning of Friday, 14th October:

Appleby-Frodingham Steel Co. (" *Seraphim* "; blast-furnaces; sinter plant; ore preparation plant)
Appleby-Frodingham Steel Co. (Steel plants and rolling mills)
John Lysaght's Scunthorpe Works, Ltd.
Richard Thomas and Baldwins Ltd., Redbourn Works
Thos. Firth and John Brown Ltd., Scunthorpe Steel Foundry
The Dragonby Ironstone Mine of The United Steel Companies, Ltd.

They were entertained to lunch by the works on each occasion. On the Friday morning ladies were also able to visit one of the works.

EXCURSIONS FOR THE LADIES

On Wednesday, 12th October, a whole-day excursion was arranged for the Ladies to visit Lincoln. During the visit they were received by the Ladies' Committee in the Assembly Rooms, saw a film on Lincoln Cathedral, and had an interesting tour of the Cathedral itself.

On Thursday, 13th, the Ladies had lunch at the Old Hall, Gainsborough, and tea at Normanby Park, by kind invitation of Lt.-Col. E. C. R. Sheffield.

A comfortable rest centre for Ladies not resident in Scunthorpe was provided at the exhibition building at Appleby-Frodingham.

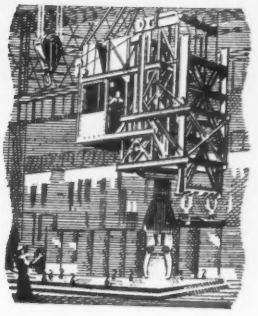
SOCIAL FUNCTIONS

In the evening of Wednesday, 12th October, a Reception was given by the Mayor of Scunthorpe, Mr. W. Albans, J.P., and the Corporation in the Baths Hall, Scunthorpe. The Mayor made a short speech of welcome to which Sir Charles Bruce-Gardner, BT., replied. After supper there was an excellent variety entertainment.

In the evening of Thursday, 13th October, Members and Ladies were entertained by The Lincolnshire Iron and Steel Institute to a Dinner and Dance at Elsham Hall, near Scunthorpe. The Hall had been kindly lent by Captain J. Elwes. Lt.-Com. G. W. Wells welcomed all the guests on behalf of The Lincolnshire Iron and Steel Institute. In his reply Sir Charles Bruce-Gardner expressed the thoughts of everybody who had attended the Meeting in saying that he was impressed by the great technical interest of the papers that had been read and of the works that had been visited and he was sure that everybody would wish him to express their thanks for the great kindness and unstinted hospitality which they had received in Scunthorpe.

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy · Plant Operation · Research



Soaking-Pit Practice

AT THE ABBEY WORKS OF THE STEEL COMPANY OF WALES LTD.

By R. H. Slade

SYNOPSIS

This paper deals with the results of 3½ years' experience of operating a battery of 20 bottom-fired Amsler-Morton soaking pits. The results show how modern advances in pit construction and instrumentation have permitted great improvements in soaking-pit heating, in regard to both fuel efficiency and steel quality.

The results are intended to augment the results of others working in this field with modern fully instrumented soaking pits of another design. Each particular design has its advantages and problems, and these results may serve as a comparison with those of other modern designs, and may also help those now embarking on the operation of modern soaking pits. 1064

PRODUCTION at the Abbey Works of the Steel Company of Wales Ltd. began in November, 1950, when the slabbing mill commenced operations. This was quickly followed by the tapping of a 200-ton furnace at the new melting shop, and the first slab going through the ten mills of the 80-in. hot strip mill. By the end of 1951 all sections had begun production, including the 3-stand cold-reduction mill, and the weekly output was built up gradually until now it is approximately 33,000 ingot tons.

Steel is supplied to the soaking pits from three melting shops—the older Port Talbot and Margam shops, which each consist of six 100-ton fixed furnaces, and the new Abbey melting shop, which at present consists of eight 200-ton fixed furnaces.

The mills are primarily intended for the mass production of rimming steel, and to a lesser degree of balanced steel up to 0·3% C, but relatively small tonnages of higher carbon steels and 0·4–4% Si steels are sometimes produced.

The steel made at the melting shops is teemed into moulds giving ingots of the following mean sizes:

7 tons	open-top	.. ..	37½ in. × 28¼ in. × 70 in.
10 ,,	,,	.. ..	48 in. × 29¾ in. × 70 in.
11·5 ,,	,,	.. ..	53 in. × 27½ in. × 70 in.
12 ,,	,,	.. ..	59¼ in. × 29 in. × 70 in.
12 tons	bottle-top	.. ..	49¼ in. × 28½ in. × 81 in.
14 ,,	open-top	.. ..	67½ in. × 29 in. × 70 in.
15 ,,	bottle-top	.. ..	51½ in. × 36¼ in. × 81 in.
16 ,,	open-top	.. ..	60 in. × 33·2 in. × 70 in.
17 ,,	,,	.. ..	67½ in. × 34 in. × 70 in.
20 ,,	bottle-top	.. ..	67½ in. × 34 in. × 81 in.

This steel is brought to the stripper bay by three diesel-electric locomotives, which also move empty trains to the cooling tracks, serve the mould-preparation bay, and provide the casting bays with prepared bogie trains.

The slabbing mill, which includes the stripper bay and soaking pits, is about 500 yd long with a 110-ft span. The stripper bay and ingot stocking area is 170 yd long, and the soaking pits extend 140 yd. There are three stripping tracks, two of these being continued alongside and to the farthest end of the soaking pits. The two stripper cranes are each of 40 tons capacity, and the two charger cranes are each of 20 tons capacity; between the stripper and charger cranes there is a general service crane of 40 tons capacity. Two cover cranes were installed for removing and replacing pit covers.

The slabbing mill is a 45-in. reversing mill capable of 2–3 drafts and rolling two 15-ton ingots in tandem (Fig. 1). The highest rolling rate to date is 450 tons/h, with a shift output record of 3050 tons, but figures exceeding this can be expected in the near future. Slabs 61 in. wide can be made, and the slab thicknesses required vary from 2½ to 8½ in. The Company is now undertaking an expansion programme which will eventually raise the weekly production to about 48,000 ingot tons. Part of this programme is the provision of another four soaking pits, a third stripper crane, and a third charger crane.

ARRANGEMENT AND DESIGN

The soaking-pit installation consists of ten pairs of one-way bottom-fired Amsler-Morton pits (Fig. 2).

Manuscript received 29th July, 1954.

Mr. Slade is Assistant Manager, Slabbing Mill, at the Abbey Works of the Steel Company of Wales Ltd.

Fig. 1—View of slabbing mill

Each pit is independently operated with its own bypass and damper, but each pair of bypasses is connected to one stack. Each pit is 16 ft 0 in. long × 14 ft 0 in. wide × 12 ft 6 in. deep, and for efficient heating 35–40% of the hearth area may be covered. This allows a pit capacity of 100 tons for the 70-in. high ingots, and 120 tons for the bottle-top or mechanically capped ingots.

Blast-furnace gas is delivered to the pits in a 69-in. gas main, under which runs the 21-in. coke-oven gas supply. At a point before the gas boosters the coke-oven main is led into the blast-furnace gas main, the amount of coke-oven gas required to give the mixed gas a calorific value of 135 B.t.u./ft^3 being regulated by an automatic valve set from the control room on the soaking-pit floor. After the gas booster a 66-in. Reaval-Askania valve controls the mixed-gas pressure to the soaking pits. A mixed gas pressure of 20 in. W.G. could be obtained, but it is preferred to operate with a pressure of 12 in. W.G. The gas main carrying the mixed gas to the pit runs directly under it where it is connected to the burner pipe situated in the burner box. Air for combustion is delivered to the pit by means of an electrically driven fan, this air being passed through recuperators capable of preheating it to 1500° F. The air enters the recuperator chamber at the bottom, circulates around the pipes, and ascends to the air tubes by means of specially selected passes. This preheated air enters the burner box via the air tubes at right-angles to the gas main. Air and gas meet at the burner nozzle and combustion takes place about 3 ft from the top of the burner block. The waste gases leave the pit by means of ducts built in the pit walls adjacent to the recuperator chambers. After entering the recuperator chambers these gases travel down the pipes and thence to the stack via the damper and bypass (Fig. 3). Since the butterfly-valve stack damper must be efficient at all times, some attention is paid to the waste-gas temperature at this point. A temperature of 1300° F is quite safe, but if the temperature, as a result of faulty combustion, exceeds 1500° F it has been found that the spindle becomes distorted and the valve inefficient.

Brickwork

The pit bottom is constructed of 37–38% alumina brick. Very little trouble has been experienced with these bottoms; only a few have needed patching or replacing of the top course. The pit linings are of single-leaf construction; 4 in. of an insulating material surround the steelwork, the inner 9-in. lining is constructed in ordinary firebrick, and the working lining in 94% silica brick (except the bottom eight courses, which are 73% alumina). Kerb blocks are 38–40% alumina, and the burner block is constructed of 73% alumina brick, this brickwork being rammed with a chrome-magnesite mixture.

Although the refractory work in the pits has been generally satisfactory, it would be untrue to say that no problems existed. At first the kerb blocks, specially shaped so as to form the sand trough as well, were made in two halves, but this allowed the sand to infiltrate between the joint and push the inner half gradually into the pit. This was overcome by having the kerb block made in one piece. It was also found that the burner block, the most vulnerable part of the pit, had an average life of six months; slag would begin to infiltrate through and interfere with the gas and air flow. By taking greater care with the drying out and perforating of the rammed mixture, together with the growing experience of pit operators and instrument attendants, it has been possible to increase the average life of these burner blocks to twelve months and some have lasted much longer. The biggest problem experienced was the excessive vertical expansion of the silica linings. It was found that the walls gradually ' grew ' over 3 in., thus exceeding the 2-in. expansion allowance left at kerb level (Fig. 4*a*). This sometimes caused the brickwork of the pit covers to rest on the kerb brick, resulting in damage to both. To overcome this problem, it was decided to leave an expansion allowance of 1½ in. six courses from the top of the pit lining, and also to leave a further 1½-in. expansion allowance at kerb level (Fig. 4*b*). These top six courses were bonded, which also eliminated any possibility of sealing sand infiltrating down between the linings, of which evidence existed, although it has caused no

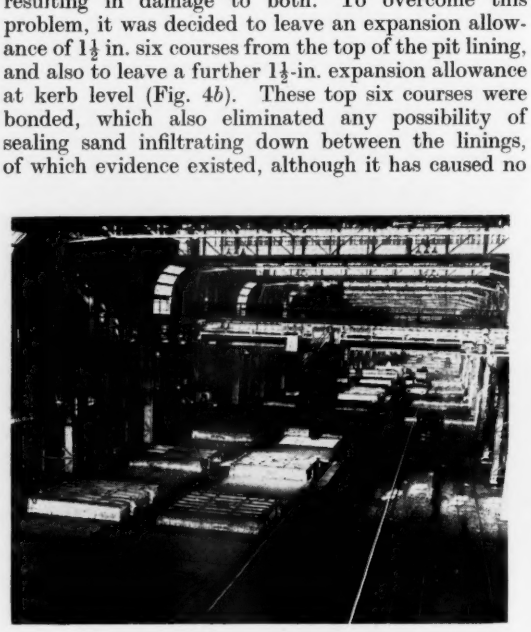


Fig. 2—View of soaking-pit installation

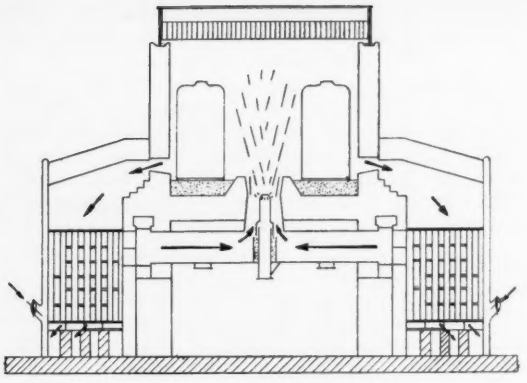


Fig. 3—Cross-section of soaking pit

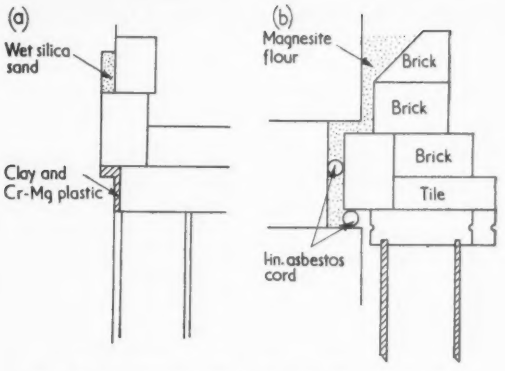


Fig. 5—Perimeter seal at top of recuperator

structural defect. Despite the problem of the excessive vertical expansion of the pit walls, the main part of the walls lasted on an average three years before requiring renewal. Then, owing to the single-leaf construction, usually only the working lining needed replacement. On the other hand, the top courses (owing to modification) and the kerb blocks have required repairs more often in the past than is expected in the future.

As an experiment one pit was lined with 40–42% alumina brick, the two leaves being tied every six courses. This lining lasted two years. In the near future it is intended to try a harder-fired 84% semi-silica brick lining for the working face of one pit. A high performance from this particular brick is expected; it would have been tried earlier, but supplies available to the Company were required elsewhere.

The soaking-pit covers are constructed with 40% alumina brick, the Frasier-Simplex method of suspension being used. Some of the covers as originally supplied are still in use, but others have needed re-bricking after periods varying between two and three years. This, however, has been due to a large extent to the lining problem mentioned. In the future it is confidently expected that an average life of 3–4 years will be obtained.

Recuperators

The recuperators are basically the most important part of the Amsler-Morton soaking pit, since they primarily decide pit performance and therefore

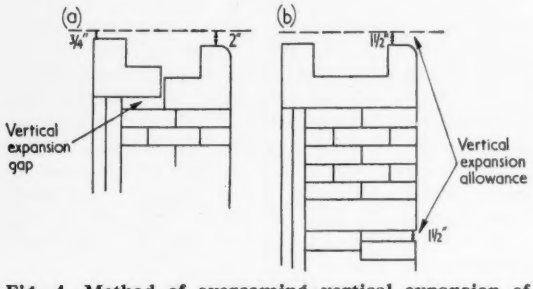


Fig. 4—Method of overcoming vertical expansion of silica linings in soaking pits

deserve a chapter to themselves. If the recuperator seals or pipes leak, not only will the pit receive insufficient combustion air, but also late combustion will tend to take place in the recuperators. This sets up an excessive temperature at the stack damper, which may cause distortion of the butterfly valve or spindle, and this in turn upsets pit pressure and makes the temperature instruments suspect.

The recuperator chambers are 14 ft long × 6 ft 6 in. wide and the pipework is 8 ft deep. The 5½ in. dia. × ½ in. thick pipes are set in six layers. All are of fireclay except the outer courses of the bottom layer, which are silica carbide designed to take the initial thermal shock. Specially shaped bricks seal and separate each layer, but some are left out at selected passes to allow the air to ascend in the recuperator.

Pit performance depends upon a high air preheat, and consequently the tile walls have to be thin to give a rapid heat transference; they are therefore likely to suffer structural damage if subjected to severe thermal shock. Great care must be taken when cooling or warming up a pit. The stronger silica carbide tiles are very expensive, and so the recuperators are a fine balance between cost, structural strength, and a high heat transference, related to pit availability.

During the second year of operation it was ascertained that air was leaking across the recuperators of some pits. This was slight and was corrected by an increase in the air ratio. The position in regard to particular pits has gradually worsened. When one of these pits was put out for repairs the recuperators were examined and it was found that the leaks were so small that they were difficult to locate. It was found, however, that the perimeter seal at the top of the recuperator was inadequate, and this was remedied by the alteration shown in Figs. 5*a* and *b*. A few pits did not respond as well as was hoped and in due course were re-examined; by use of an air test it was possible to locate and assess the severity of the leaks in the pipes.

Recently it was decided to replace the first pair of recuperators; the remainder will be replaced as it becomes necessary. This will probably mean a programme of gradual replacement during the next two or three years, and will give an average recuperator

life of about five years. It is believed that there is no reason why the average life of such recuperators should not be greater. This problem is continually being investigated, but at present insufficient data are available to state accurately how this may be achieved.

The standard of efficiency demanded of a recuperator can be lowered— i.e. its life can be increased if all other parts are functioning properly. Again, it may be possible to improve the design of the burner port to aid this, and an investigation of this problem is now being undertaken. Furthermore, leakages in the recuperators mean that more air has to be delivered to the pit to allow for losses, but this is only possible if excess capacity exists in the stack design. To obtain further information on the behaviour of recuperators it is intended to install oxygen meters and additional temperature recorders.

Gas Preheaters

Pits 1 and 2 were equipped with gas preheaters in addition to the air recuperators, to provide data for similar installations on all pits.

The preheaters were constructed in the twin bypass to the stack. They were needle-type recuperator and the chamber (7 ft square × 4 ft high) contained 40 pipes. The gas entered at one end, travelled through the pipes, and was then conducted by a lagged gas main to the pit. The waste gases passed between the recuperator pipes and exhausted to the main stack.

To prevent the temperature of the gas reaching a dangerous point an air-dilution system was provided. This was automatic, so that when the temperature of the waste gases reached the maximum desired (i.e. the temperatures at which the controls were set), an air fan was operated, which forced cold air through four ducts at the base of the stack to mix with the waste gases. The waste-gas temperature control was set at 1000° F, but since the waste-gas temperature rarely reached this figure at the preheater the air-dilution system was simply a safety measure. The temperature of the preheated gas was about 600° F.

It was found that as a result of the drop in gas pressure across the preheaters the maximum input of gas to these two pits was about 25% less than that of the others, yet the heating rate was equal to that of the other pits. This meant that, although there was no gain in heating rate, a saving of about 20% in fuel was achieved.

After eighteen months the performance of pit 2 deteriorated. Tests showed that the preheater pipes were leaking. They were taken out and found to be badly corroded and in some cases distorted, especially at the gas entry end. The pipes were metallurgically examined, and it is believed that damage was caused by sulphur present in the coke-oven gas. A few months later pit 1 suffered the same fate.

Whether gas preheaters are desirable or not depends largely upon the calorific value of the gas available and the cost within a works. It is believed that when using coke-oven gas the most likely material to withstand or prevent this corrosion is a 30% Cr iron. Such preheaters would be very costly and to be worthwhile would have to last a minimum of four years. Furthermore, if a reasonable life is not obtained, in addition to the capital cost a great burden is placed on the engineering maintenance staff, since nuts and bolts are legion and individual pipes are very difficult to replace. Moreover, if such preheaters become inefficient the only sure remedy, especially when thinking of the engineering work involved, is complete replacement.

Coke-Breeze Bottoms

The pits were designed for the use of coke-breeze bottoms. The breeze (0–$\frac{1}{2}$ in. dia.) is brought by lorry and stacked in a bunker of 320 tons capacity situated outside the main building. From the bunker the coke-breeze is loaded into a hopper of 10 tons capacity by means of a grab crane. The coke-breeze bells, of 5 ft 6 in. dia. and 2 tons 5 cwt capacity, are filled from this hopper. The contents of two breeze bells are needed to make a breeze bottom approximately 15 in. deep.

Before the breeze bells are filled, the doors at the bottom of the bell are closed; they are kept closed by the simple expedient of tying the handles together with cord. A fitting at the top of the bell allows easy handling by the charger cranes. When required, the bell is taken into the pit by one of the charger cranes and held in one corner 7 in. from the floor of the pit. When the cord securing the handles burns away the breeze is deposited on the pit floor, the bell is taken slowly around the pit. When the crane has made a full circuit of the pit the bell is empty, and a smooth carpet of breeze about 7 in. deep has been laid on the pit bottom. This is repeated holding the second bell 7 in. above the first layer of breeze. Experienced crane drivers can make a perfectly level bottom in 10 min.

When cleaning out a pit bottom a cinder bin of 30 cwt capacity is placed under each of the four cleaning-out holes by a battery-operated truck. The cinder-hole doors are opened by a mechanical device. The cinder in the holes and in the area around the holes falls into the bins, and the remainder is brushed to the nearest holes by means of a tool fitted to the charger-crane tongs; cleaning takes about 10 min. The cinder bins are taken to the cinder disposal bay, cooled, and then loaded. As the cinder is loaded it is screened to separate any brick, rubble, or slag, and this cinder is then despatched to the power plant for further use.

During the first two years' operation, the bottoms were remade every four days, but now they are remade every five days. For the amount of slag that is made this cleaning cycle could be extended further, but it has been found that after the fifth day the bottom begins to wear thin and in an emergency would not be effective. Again, it is much better to clean a five-day bottom in 10 min than to take much longer over an eight-day bottom and possibly incur some damage as well. A poker for cleaning slag from the cleaning-out holes is kept but has very rarely been needed.

The weekly consumption of coke breeze is 120 tons, so with the present output 280 tons of steel is produced

for every ton of coke breeze used. Since some of the cinder is salvaged the cost per ton of steel is lower still.

Experiments are being carried out with a wet bottom to examine whether or not the existing method is the better. Without discussing at length the controversial subject of wet *v.* dry bottoms, it is interesting to note that if the time factors that can be fairly easily measured are equal, the decision rests upon factors more difficult to measure, such as possible damage to brickwork when digging the slag bottom out, possible mechanical damage to charger cranes when cleaning dry bottoms, and electrical delays to cranes caused by rising dust.

AUTOMATIC CONTROL

Except when lighting up a repaired pit or on the rare occasions when an instrument becomes defective, the soaking pits are automatically controlled. Temperatures, gas flow, and pit pressures are recorded on standard charts. The speed of operation would make it impossible for it to be otherwise with the existing manning.

A pit-pressure regulator is situated in the pit wall above one recuperator, about 3 ft from the top. In a similar position on the opposite wall a top temperature-controlling couple and a top temperature-recording couple are located. At the bottom of the pit in the corner exhaust ducts temperature-recording couples are placed. In addition, two opposite corners contain temperature-controlling couples.

When a pit is charged the top temperature controller is set at 2430° F and the bottom controller at 2300–2350° F. When the bottom temperature set is attained the recording couples will tend to vary between 2275° and 2350° F, giving a mean of 2320° F. Furthermore, the gas flow is automatically reduced, the gas valve governs the air valve, and this in turn reduces the air flow. The gas flow gradually falls to a minimum input of about 30,000 ft³/h and remains at this figure until the ingots are drawn. This minimum gas flow simultaneously replaces the heat lost through radiation. The accuracy of the estimated steel temperature depends on the validity of the theory that after a certain soaking period the steel temperature throughout equals that of the waste gases passing the thermocouples in the exhaust ports. The top temperature controller can also reduce the gas flow if required, but in this type of pit it is no accurate guide to steel temperature, being used only as a safety measure.

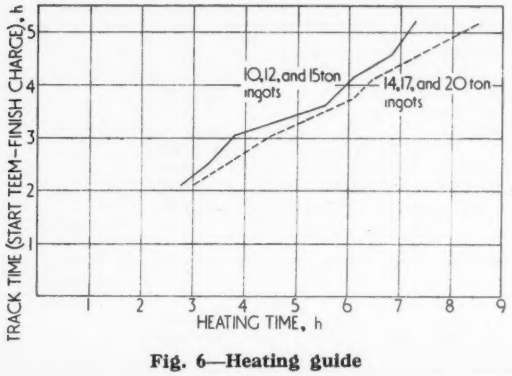


Fig. 6—Heating guide

The required soaking period can be decided by the period the gas flow has been held at a minimum, but the management prefer to determine the soaking period by relating it to the track time. The soaking period used to be decided by adding 1 h to the track time, but now it is preferred to work to finer limits, and soaking-pit heaters have been supplied with a suitable guide (Fig. 6). There is little or no difference in the temperature of the first and the last ingot drawn, since if the temperature falls after drawing an ingot, the heat lost is immediately replaced when the cover is put back on the pit by the maximum gas input being immediately introduced if necessary.

OPERATING DETAILS

The slabbing mill operates for 19 shifts each week: 6 A.M. Sunday to 1 P.M. Saturday. Since the three melting shops operate continuously, the stripper bay and soaking pits have to operate on a similar basis. Each Saturday morning as many pits as possible are emptied; these take the first part of the 'weekend' steel, and are then set at 1800° F and kept at this temperature until Saturday midnight, when they are brought up in sequence for Sunday morning rolling.

The remaining 'weekend' steel (usually about 2500 tons or 7½% of the weekly make) is stocked. This cold stock is charged into the soaking pits at the first opportunity and is usually cleared by the middle of the week. When this is completed, 12–14 pits are sufficient to accommodate the incoming hot steel. The remainder, apart from the one or two that may be out for repairs, are held at 1800° F until the following weekend. These pits held at 1800° F are useful to cushion any emergency, such as a traffic derailment, crane breakdown, or mill delay, since they can be brought quickly to operating temperature if required. Again, with this excess pit capacity available during the latter half of the week, it is possible at some periods to hand over the mill or cranes to maintenance engineers and so ease weekend repairs, and yet not fall behind the melting-shop production.

Finally, the management considers that cooling pits too often is inadvisable. Frequent expansion and contraction of refractory work induces structural weakness and may cause defects very difficult and costly to locate. To obtain the best refractory and fuel results from these pits, they must be operated as far as possible on a continuous basis. This will be necessary when the present expansion programme is complete and weekly production is increased by about 35%.

MANNING

One shift foreman is responsible for the supervision of the stripper bay, the soaking pits, and the slabbing mill. The soaking pits are directly controlled by one heater, and the other two operators are a bottom maker and a cinderman. These two men are responsible for operating gas valves when required, maintaining the sand seals, inspecting burner pipes,

Table I

WEEKLY THROUGHPUT OF SOAKING PITS

Week Ending	Tonnage Heated	Idle Pit Hours*
9.1.54	31,663	1154
16.1.54	32,208	808
30.1.54	31,602	898
6.2.54	30,676	977

* These figures include 340 idle pit hours incurred at the weekend, which would be reduced to 180 idle pit hours with the introduction of a 20-shift week in the mill.

servicing the coke-breeze bells, changing tong bits, cleaning up in the basement, and disposing of the cinder after bottom making.

There is one driver for each of the two charger cranes; since the work is continuous they are relieved for meals. A steel planner who is constantly in communication with the ingot controller and the steel plants organizes the work of the charger and cover cranes. He also supervises the charging of the ingots, which are of various grades and sizes. A pit recorder is responsible for all the office records and communication with the mill personnel, by means of Lamson tube and speaker systems.

An instrument attendant is shared between the soaking pits and the hot strip mill reheating furnaces, and a small staff of fuel technologists are available when required.

TRACK TIMES

For the purpose of this paper track time refers to the period elapsing from the time a furnace is tapped to the time the ingots are charged into the soaking pits. Track time is well recognized to be one of the major factors in deciding fuel efficiency.

In a large modern plant working mainly large rimming steel ingots, track time is an ever-present problem. In the first place, there is a minimum time in which it is safe to move or strip moulds containing rimming steel. Secondly, when steel is continuously being moved in large quantities, it only requires an interruption along the line (such as a traffic, crane, or mill delay) for track time to be seriously affected. Average track time at present is approx. 3 h 15 min. In the expansion programme of the Company additional cranes are being provided, and this will reduce still further the hazards related to track time. However, how much track time can be improved is beyond the scope of this paper.

The following soaking-pit heating summary is an example of present performance (this summary does not include hot steel held in the soaking pits over the week-end or cold steel charged during the week):

Tons Heated	No. of Heats	Average Track Time	Average Time Charge in Pits
28,238	278	197 min	309 min

PIT EFFICIENCY

Heating Rate, Fuel Consumption, and Quality

The Amsler-Morton soaking pit is at its best when operating with hot steel; e.g. steel with a track time of 2—2½ h can be heated at a rate exceeding 40 tons/h at a fuel consumption of less than 4 therms/ton. On the other hand, the heating rate for cold steel is approximately 8 tons/h.

Table II

SOAKING PITS—THERMAL CONSUMPTION

These figures are the overall consumption, which includes charging, drawing, and all pit hours idle.
Mixed gas ratio: 10 parts blast-furnace gas to 1 part coke-oven gas.

Week Ending	Tonnage	Consumption, B.t.u./ton	Cold Steel Charged	
			Tons	%
10.1.54	31,663	822,900	1458	4·8
17.1.54	32,208	796,900	2555	7·9
24.1.54	32,494	961,700	4542	14·0
30.1.54	31,602	790,300	2273	7·2
6.2.54	30,676	825,000	2281	7·4
13.2.54	29,969	803,000	2226	7·4
20.2.54	29,339	770,000	2021	6·8
27.2.54	30,498	765,000	2457	8·1

During the first three years' operation output was restricted, traffic facilities were inadequate, and teething troubles were experienced with stripper and charger cranes. All this, together with holding time between shifts since the mill was not worked continuously, resulted in the weekly fuel consumption being 10–10·5 therms/ton.

Since December, 1953, weekly production in the slabbing mill has exceeded 32,000 tons. All causes of poor track times or long holding times have been eliminated or considerably reduced, and the fuel consumption has now been reduced to 8½ therms/ton. This figure is the overall consumption and includes the gas used for holding the pits over the weekend and the idle time during the week which, as Table I shows, sometimes exceeds 1000 pit hours per week.

From the fuel consumption figures, given in Tables II and III, it can be concluded that if sufficient steel was available to operate these pits at their maximum capacity, with a 20-shift working week the fuel

Table III

INDIVIDUAL PIT PERFORMANCE

The figures are the overall consumption, which includes charging, drawing, and all idle pit hours.
Mixed gas ratio: 10 parts blast-furnace gas to 1 part coke-oven gas.

Week Ending	Pit No.	Tonnage	Cold Steel, %	Consumption	
				B.t.u./ton	Remarks
10.1.54	1	2308	4·9	628,000	
,,	2	2047	5·2	806,000	
13.2.54	3	2314	..	665,000	
30.1.54	5	2234	2·7	600,000	
20.2.54	7	2027	5·8	641,000	
,,	8	2268	..	572,000	
10.1.54	9	2303	..	660,000	
27.2.54	10	2234	4·7	630,000	
,,	11	2358	..	477,000	One recuperator replaced
20.2.54	14	2816	..	505,000	Both recuperators replaced
16.1.54	16	2132	4·5	750,000	
27.2.54	17	2068	5·6	594,000	

consumption could be reduced to 5–6 therms/ton, and the soaking pit throughput, after allowing for diminishing returns, would be about 45,000 tons.

An important aspect of soaking-pit heating that cannot be neglected when producing high-class sheet for the motor-car and tinplate trade is steel quality. It is necessary to provide an oxidizing atmosphere, yet this is a danger, particularly when manufacturing rising steel, since this type of ingot tends to have a thin skin and so overscaling may expose blowholes. Long soaking times at rolling temperature must be avoided as far as possible. When mill delays occur, pits containing this steel are carefully watched and where possible are held at 2100° F or lower; they are eventually brought up for rolling to a time table consistent with mill requirements.

Heating—Experimental

Much has been written on the subject of whether or not it is advisable to charge ingots with liquid centres in fired soaking pits. If this can be done the heat inherent in the ingot can be allied to the external application of heat, thus reducing fuel consumption.

It was found that when bottle-top ingots of a very short track time (2¼ h tap to charge) were charged and the pit was fired with the maximum gas input, blistering occurred when rolling. If the ingots were charged and normal firing conditions were not introduced until the pit temperature began to fall (approximately 1 h), given an average heating time the rolling heat was not good, presumably because the inside temperature of the ingots had fallen below that required for good rolling, and insufficient time was allowed in the pit to replace this. Thus this method meant a reduction in fuel consumption at the expense of heating rate.

Further experiments were carried out using a small input of gas for periods varying from 1 to 2 h instead of leaving the pit unfired. Finally it was found that eight ingots at 15 tons could be heated in 3–3½ h at a fuel cost of approximately 2 therms/ton if the gas input for the first 1½ h is reduced to 33% of the normal maximum. No blistering or lamination was encountered.

It is intended in the near future to investigate this problem more fully, and so provide more exact data. The difficulty in such a problem is to decide when the rapid fall of the internal ingot temperature takes place.

Acknowledgments

The author desires to express his thanks to the Assistant Managing Director of the Steel Company of Wales Ltd., Mr. W. F. Cartwright, for permission to publish this paper, and to Mr. H. H. Ascough, Rolling Mills Superintendent, for his personal encouragement and help in compiling this paper.

The Effect of Temper-Rolling on the Strain-Ageing of Low-Carbon Steel

By H. P. Tardif, B.A.Sc., M.Sc., Ph.D., and C. S. Ball, B.Met., Ph.D., A.I.M.

SYNOPSIS

The activation energy of the strain-ageing process has been measured using the elongation at the yield point to determine the extent of ageing. The two methods of pre-straining which were compared were stretching in tension and temper rolling. The rate of return of the yield-point elongation has been compared with the increase in hardness and yield stress under the same conditions. Further experiments have been made to establish the cause of the retardation of the return of the yield point after temper rolling and it has been suggested that it is due to the orientation of micro-stresses in the pre-strained material. It has been pointed out that no single mechanical property may be used to determine the beginning or end of the strain-ageing process although there were no significant differences between the activation energies measured from changes in hardness, yield stress, or yield elongation. Evidence was found to suggest that the return of the yield-point elongation on ageing may be a two-stage process. 1115

Introduction

THE FORMATION of stretcher-strain markings in low-carbon steel pressings is well known, as is the fact that these markings are due to the elongation at the yield point. Although the configuration of the markings must vary, being determined by the strain distribution in the pressing, the severity of the defect may be related quantitatively to the yield-point elongation.[1] Normally sheet steel is subjected to enough cold deformation to eliminate the yield point before pressing, but both the type of deformation and the time interval between pre-straining and pressing may vary. Ageing after straining will in general cause a return of the yield point, and it has been observed that the mode of deformation influences the rate and the extent of the return.

In practice, the pre-straining of low-carbon steels is usually carried out by temper rolling, roller levelling, or occasionally by stretching and it has been generally

Manuscript first received on 13th September, 1954, and in its final form on 21st February, 1955.

Dr. Tardif is Physical Metallurgist at the Canadian Armament Research and Development Establishment, and Dr. Ball is Assistant Chief Metallurgist of the Steel Division of the Steel Company of Wales, Ltd.

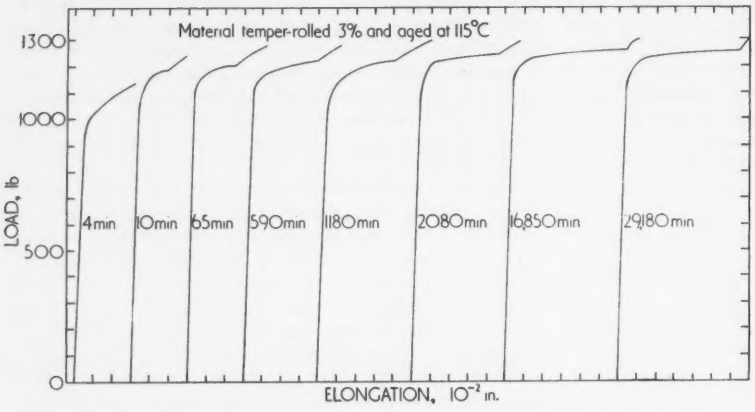


Fig. 1—Load/elongation curves for material aged after temper rolling

observed that, for a given set of ageing conditions, temper rolling is the most efficient method and stretching the least efficient method of delaying the return of the yield-point elongation. Recently interest has been aroused in the effect of the residual stresses, left by pre-straining, on subsequent ageing; Polakowski[2] has suggested an explanation for the effect of different modes of pre-straining and this has recently been amplified by the experimental work of Hundy.[3] Their explanations are based on the postulation that if residual stresses of sufficient magnitude are present, the yield point observed on the extensometer is obscured by differential yielding at various points in the specimen. This type of explanation fits the above observations since stretching in pure tension should not leave any appreciable body stresses whereas cold rolling gives rise to a balanced system of internal stress. On the other hand, Tipper,[4] whilst realizing that the yield point may be affected by internal stresses, has doubted that the theory of yielding advanced by Cottrell and Bilby[5] was compatible with the evidence of the directional effect of pre-straining on subsequent changes during ageing.

The strain ageing of low-carbon steels has been studied by many workers and several theories have been advanced. This paper will only refer to these theories to explain the results, but it must be pointed out that the return of the yield point with ageing is most satisfactorily explained by a mechanism involving the anchoring of dislocations, and in any case the mechanism must postulate the diffusion of carbon or nitrogen in α-iron to account for ageing. During the ageing process changes take place in a number of physical and mechanical properties and if the change

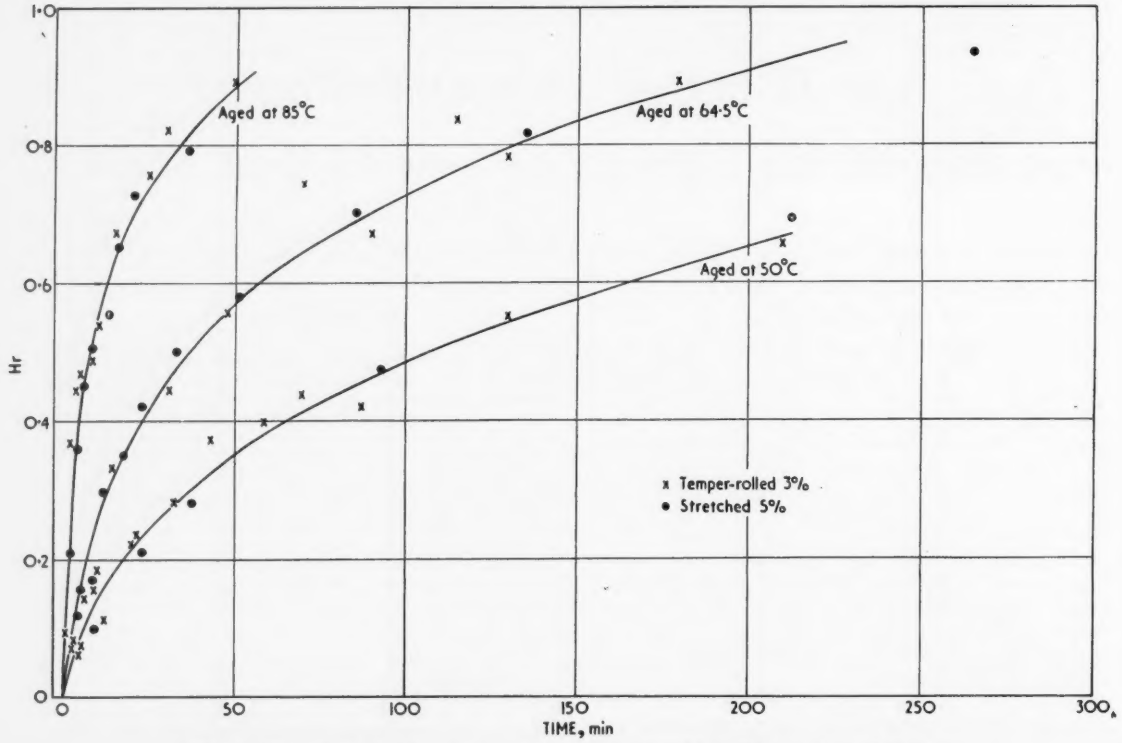


Fig. 2—Change in hardness on ageing after temper rolling and stretching

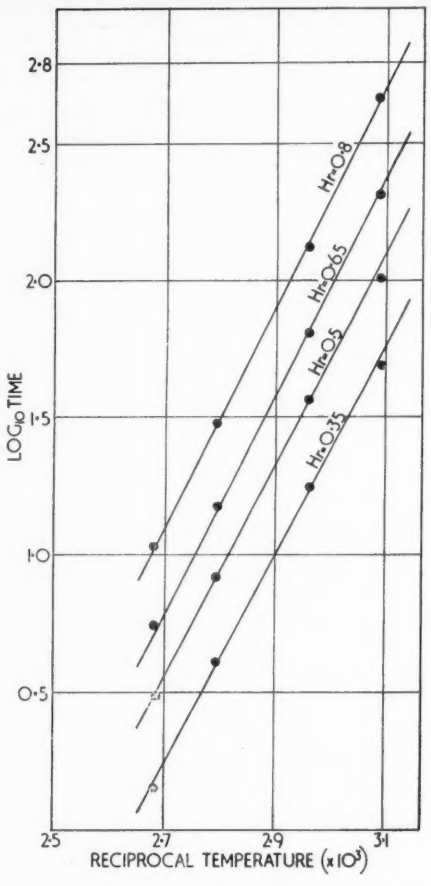


Fig. 3—Activation energy curves from hardness measurements for different values of H_r

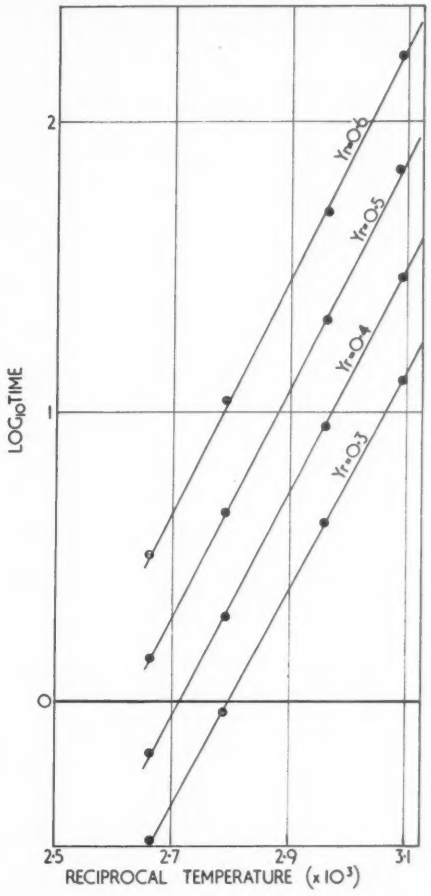


Fig. 5—Activation energy curves for yield-stress measurements for different values of Y_r

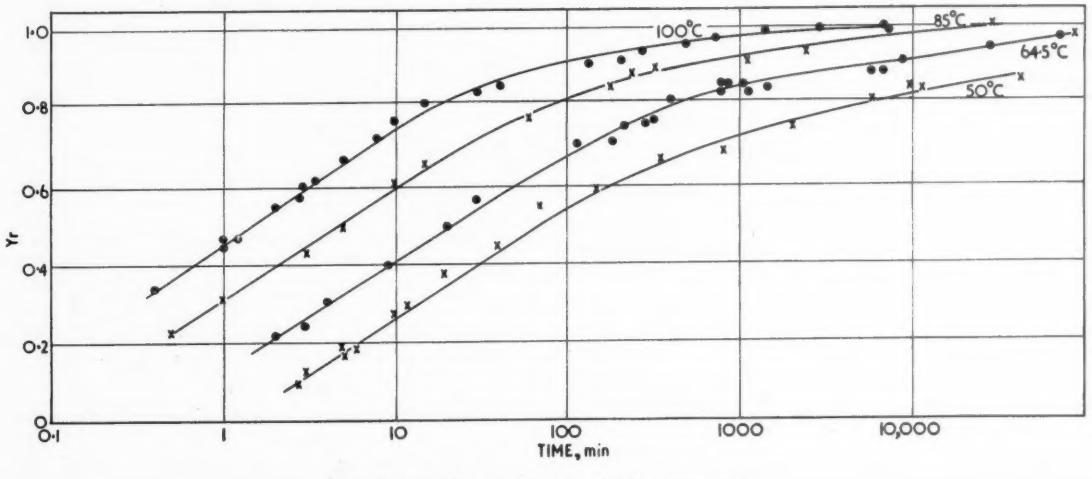


Fig. 4—Ageing curves for yield-stress ratio

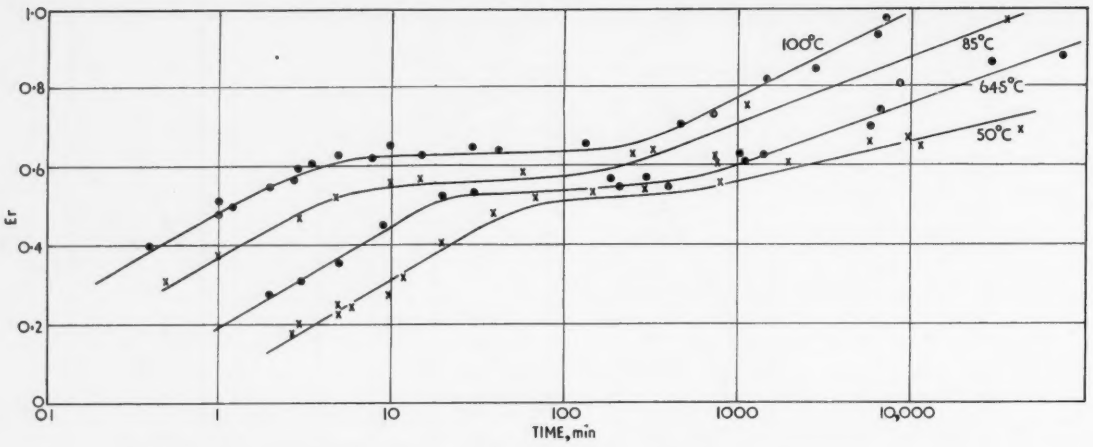


Fig. 6—Ageing curves for yield-point elongation measurements (pre-strained specimens)

in any one property is measured as a function of time and temperature the activation energy of the process may be measured since, if the process is controlled by diffusion, the relationship between time and temperature should be of the form:

$$t = A \exp Q/RT$$

where A = constant, R = gas constant, Q = activation energy, T = absolute temperature, and t = time for the process to reach an arbitrary stage.

Most commonly the kinetics of strain ageing have been studied in terms of hardness,[6] electrical resistivity,[7] damping capacity,[8] and tensile tests,[3,9] and values of the activation energy have been obtained which correspond to a process involving the diffusion of carbon or nitrogen in ferrite. In most cases the results have also supported the argument of a dislocation mechanism.[7,9]

It is surprising that up to the present time a full study of the kinetics of strain ageing using the yield-point elongation as a criterion of the degree of completion of the process has not been reported. For this reason it was decided to measure the rate of return of the yield-point elongation in a low-carbon steel in some detail. From the above it will be seen that a measurement of the activation energy of the process in this way would also decide whether or not any explanation for the differences in ageing characteristics following different methods of pre-straining should be sought outside the basic ideas advanced by Polakowski[2] and Hundy.[3] The experiments were confined to temper rolling and stretching in pure tension since it was felt that the mechanism of deformation by roller levelling was not sufficiently understood for any fundamental observations to be made.

EXPERIMENTAL TECHNIQUES

The number of experimental results required to establish the value of an activation energy is large and therefore conditions were standardized so that the only two experimental variables were ageing time and ageing temperature following two conditions of pre-straining. The range of variables was later extended but the ageing curves showed the same general characteristics.

A standard deep-drawing quality steel was used, the composition being 0·053% C, 0·31% Mn, 0·028% S, 0·018% P, trace Si, and 0·005% N. Standard B.S.485 strip test pieces were blanked from sheet which had been annealed at a thickness of 0·19 in. and cold-rolled to 0·070 in. in passes of less than 5% reduction in area, the direction of rolling being reversed after each pass.

The edges of the test pieces were filed and polished. It was decided to temper-roll the actual test pieces to avoid unnecessary ageing at room temperature and also the possibility of edge effects due to blanking lightly rolled sheet.

It was essential that quench ageing be eliminated, so that after the test pieces had been prepared from the cold-rolled sheet they were annealed for 4h *in vacuo* at 850° C and furnace-cooled, producing a yield-point elongation of 3–4%. No quench-ageing effects were detected after this treatment.

The preliminary stretching and the final testing were carried out on a specially constructed machine, which incorporated a rigid beam for measuring the applied tensile force, so that a small extension of the test piece could give rise to a large relaxation of stress, the measured yield stress and yield elongation being therefore independent of the characteristics of the machine.[10] A standard strain rate of 0·0022 per min was used throughout. The test pieces were aged at temperatures up to 115° C in thermostatically controlled oil baths with a temperature control better than ± 0·25° C. The mill used for temper rolling was a two-high reversing strip mill with 14-in. dia. smooth rolls. The rolling speed was 40 ft/min and the rolls were degreased for the operation. The temper-rolling reduction was carried out in one pass.

RESULTS

The rate of ageing was studied after pre-straining in two ways: 5% tensile elongation and 3% reduction in thickness by rolling. Ageing temperatures of 50°, 64·5°, 85°, 100°, and 115° C were used although it

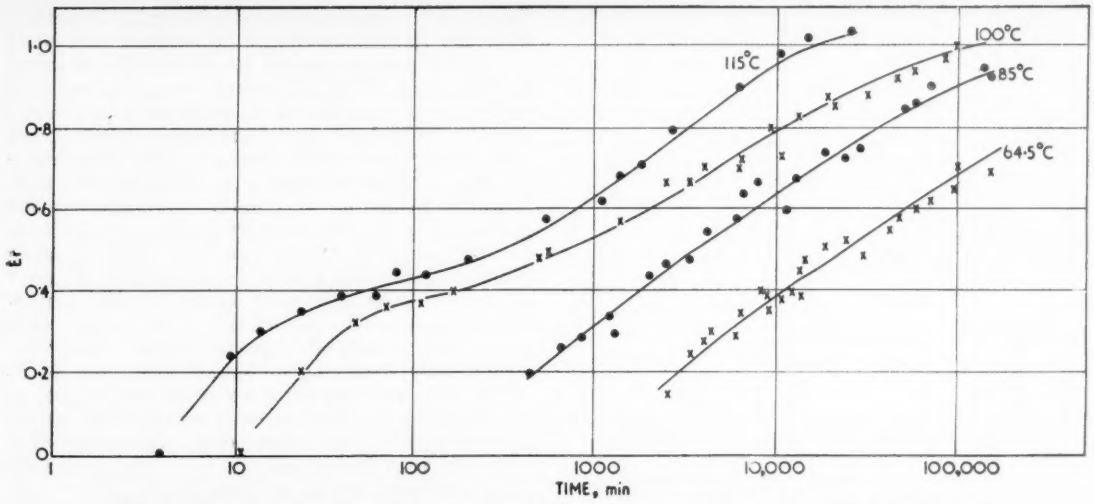


Fig. 7—Ageing curves for yield-point elongation measurements (temper-rolled specimens)

was not practicable to compare the effect of the two methods of pre-straining on the yield-point elongation after ageing at the lowest and the highest temperature owing to the wide disparity in the rates of ageing.

Some scatter was observed when measuring the load required to pre-strain the test pieces in tension, in the initial elongation at the yield point, and in the initial hardness because of the slight inhomogeneities of the rimming-steel sheet. The mechanical properties measured were therefore expressed in the form of the following functions which are a measure of the extent of ageing at a given time:

$$\text{Ratio of change in hardness} = H_r = \frac{H_t - H_0}{H_m - H_0}$$

where H_t = hardness after ageing for time t
H_0 = hardness immediately prior to ageing
H_m = maximum hardness after full ageing.

$$\text{Ratio of change in lower yield stress} = Y_r = \frac{Y_t - Y_0}{Y_m - Y_0}$$

where Y_t = lower yield stress after ageing for time t
Y_0 = stress required to pre-strain by 5% elongation
Y_m = lower yield stress after full ageing.

$$\text{Ratio of change in yield elongation} = E_r = \frac{E_t}{E_0}$$

where E_t = elongation at yield point after ageing
E_0 = elongation at yield point in annealed condition.

Table I

ACTIVATION ENERGY VALUES

Method	Activation Energy, cal/mole
For temper rolling:	
Hardness	18,060
Yield-point elongation*	19,700
For tensile elongation:	
Hardness	18,200
Yield stress	18,700
Yield-point elongation†	18,780

* Above horizontal step
† Above and below horizontal step

Since other workers have confirmed the theoretical prediction that the maximum yield stress and hardness which can be achieved by ageing in the region 0–100° C are essentially independent of ageing temperature, the values of H_m and Y_m were taken as the mean of those obtained by full ageing at 100° C. The values of H_r and Y_r will obviously not exceed unity, whereas the value of E_r may do so. H_r could be obtained directly on every test piece. The individual yield elongation before rolling could not be measured and therefore the value of E_0 was taken to be the same as the mean of the large number of results obtained when stretching in tension. It was considered undesirable to attempt to estimate Y_0 in the case of the temper-rolled test pieces. Figure 1 shows a typical series of results obtained when temper-rolled test pieces were aged for various times at a constant temperature and is included to illustrate the type of result which was obtained.

HARDNESS AFTER STRAIN AGEING

Before ageing, the hardness of all the annealed test pieces varied between 83 and 88 H_D, that of the stretched test pieces between 98 and 103 H_D, and the surface hardness of the rolled test pieces between 96 and 101 H_D. The increase in hardness on full ageing was similar in both cases and was not sensibly affected by an increase in ageing time from 100 to 5×10^4 min.

Figure 2 shows the values of H_r for both temper-rolled and stretched test pieces plotted against time for the earlier stages of three ageing temperatures. It can be seen that there was no apparent difference in rates of ageing when measured in terms of hardness changes. To measure the activation energies the times taken to reach the ageing stages defined by $H_r = 0{\cdot}8$, $0{\cdot}65$, $0{\cdot}5$, and $0{\cdot}35$ were determined and Fig. 3 shows the corresponding activation energy curves for the temper-rolled test pieces. As would be expected from Fig. 2, no significant difference was found between the effects of either method of pre-straining. The activation energy values are given in Table I.

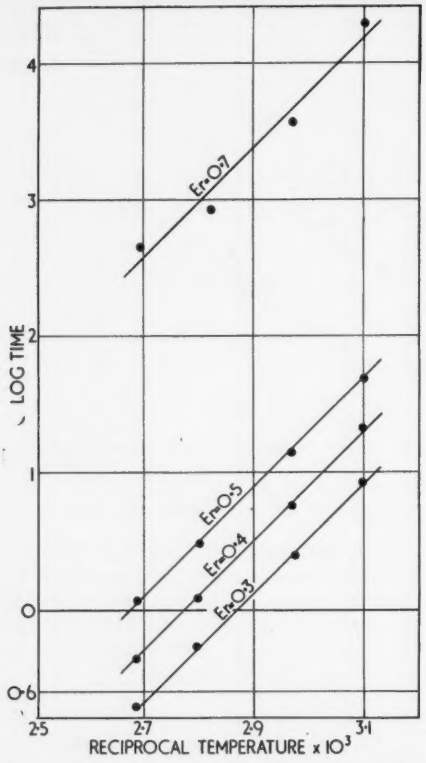


Fig. 8—Activation energy curves from yield-point elongation measurements of stretched specimens: $E_r = 0{\cdot}3$, $0{\cdot}4$, $0{\cdot}5$, $0{\cdot}7$

EFFECT OF AGEING ON LOWER YIELD STRESS

Figures 4 and 5 show the results obtained from the stretched and aged test pieces and demonstrate that the maximum value of the yield stress when fully aged in this temperature range is independent of ageing temperature. As in the case of hardness it would appear that the activation energy for the majority of the process remains unaltered. The values of the activation energy determined from Fig. 5 are listed in Table I.

It was considered inadvisable to base any exact calculation on the increase in yield stress consequent on ageing after temper rolling because of the doubt which must surround the estimated value of the yield stress after temper rolling and before ageing. A qualitative comparison may be allowed by equating Y_0 to the value of the mean stress required to cause 5% extension in tension. On this basis the rate of ageing after temper rolling was very similar to that following stretching. Figure 1 demonstrates the increase in yield stress after temper-rolled test pieces were aged for 10 min at 115° C. This resembles the high proportional increment found on ageing the stretched test pieces at the higher temperatures of Fig. 4.

EFFECT OF AGEING ON RETURN OF YIELD-POINT ELONGATION

The rate of return of the yield-point elongation is shown for the test pieces pre-strained in tension in Fig. 6 and for those temper-rolled in Fig. 7. As distinct from the continuous change of hardness and yield stress with time at constant temperature it was found that on ageing after stretching the elongation returned to 50–60% of the value in the annealed condition in a comparatively short time at any temperature followed by a considerable period when no appreciable change took place. After this step in the curve the elongation continued to increase. Similar observations were made in the case of the temper-rolled test pieces when aged at 100° and 115° C, but the delay was of much shorter duration and was not so well marked. Figure 7 suggests that ageing at 64·5° and 85° C after temper-rolling gives rise to the latter portion of the curve only. When measuring the activation energy for ageing after stretching in tension, one value of E_r above this step and three below it were taken, as shown in Fig. 8. The activation energy of the ageing process after temper rolling could only be measured with any reasonable accuracy above the horizontal step. The latter results are shown in Fig. 9.

DISCUSSION OF RESULTS

The values of the activation energies measured by these three different criteria agree with those of other workers. The rate of return of the yield-point elongation would therefore appear to depend on the rate of diffusion of carbon or nitrogen. In addition, it appears that within the range examined the mechanism which causes the yield-point elongation to return on ageing is independent of the method of pre-strain, although the absolute measured value, as this paper will suggest, depends upon it.

These results raise two questions: firstly, concerning the relationships between the different methods of following the strain-ageing process; and secondly, the shape of the ageing curve when measured in terms of the yield-point elongation. Figures 10 and 11 give a comparison between the three different manifestations of strain ageing when stretched test pieces were aged at 50° and 100° C, respectively. In both cases there was a change in the yield stress and the elongation at the yield both before the hardness had started to

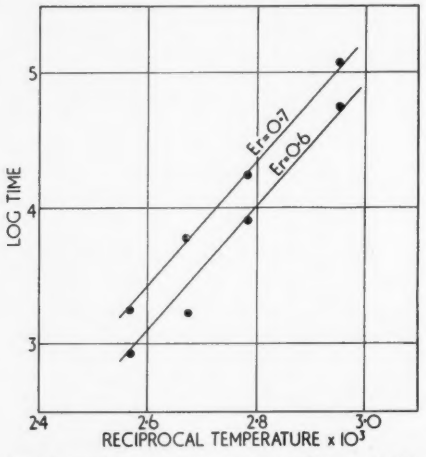


Fig. 9—Activation energy curves from yield-point elongation measurements from temper-rolled specimens: $E_r = 0{\cdot}7$ and $0{\cdot}6$

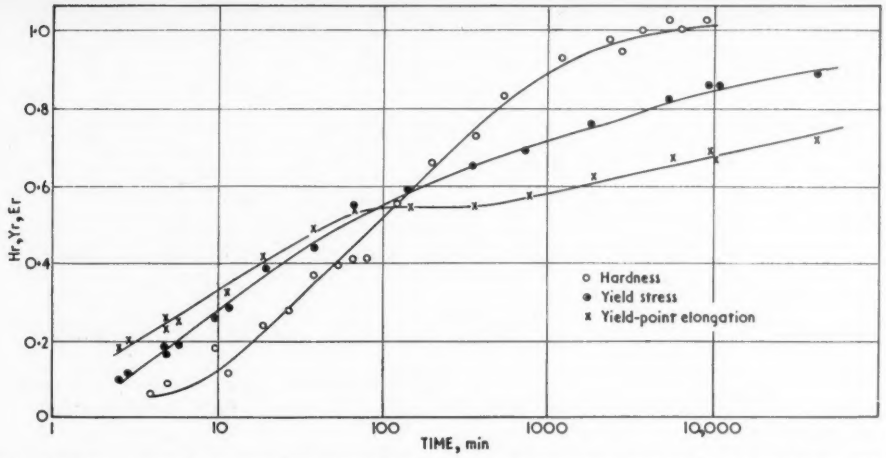


Fig. 10—Comparison between simultaneous changes in properties during strain ageing at 50° C

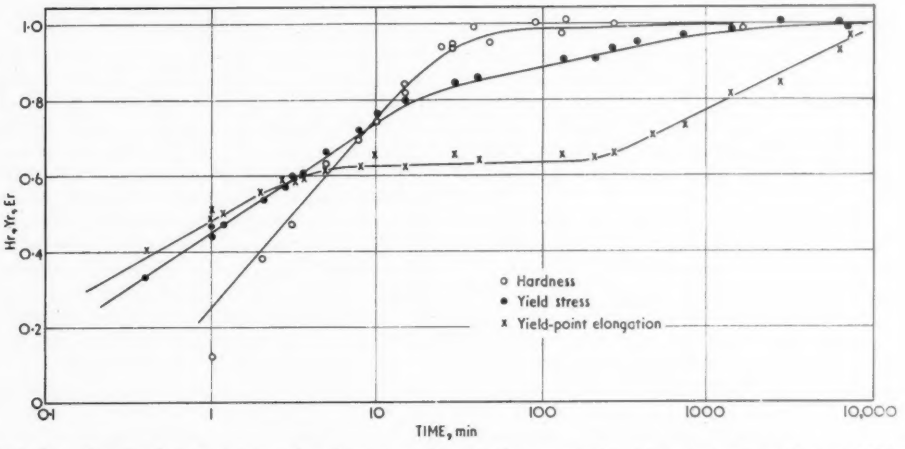


Fig. 11—Comparison between simultaneous changes in properties during strain ageing at 100° C

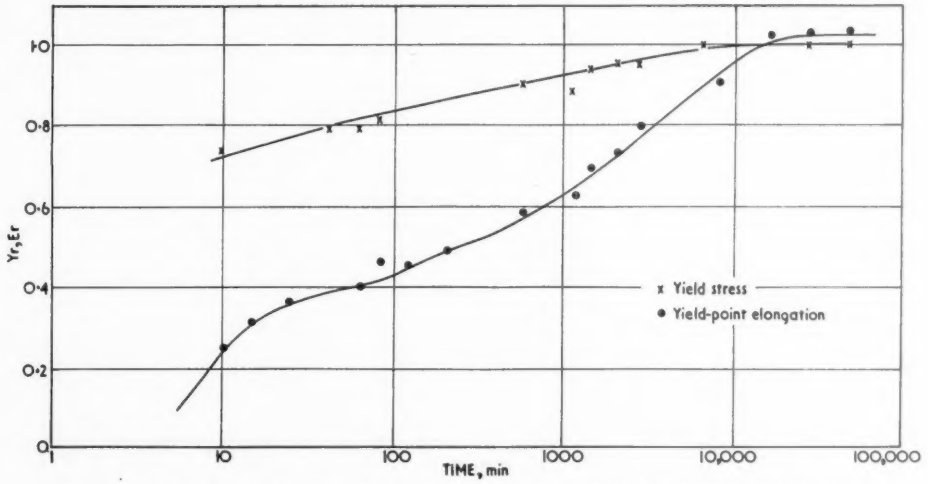


Fig. 12—Ageing curves from yield stress and yield-point elongation measurements

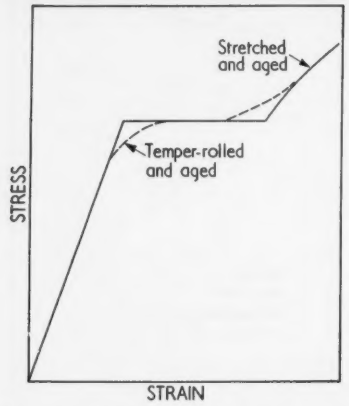


Fig. 13—Schematic illustration of the effect of internal stress on stress/strain curves after ageing

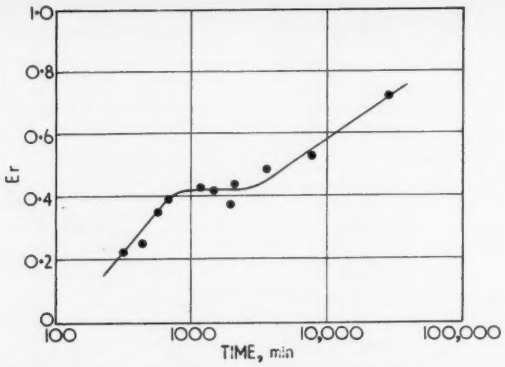


Fig. 15—Strain-ageing curve of transverse test pieces aged at 115° C

increase and after the maximum hardness had been reached. The results of Figs. 10 and 11 are typical of all the other ageing temperatures and can be explained on the basis that the hardness test measures the resistance to large plastic strains rather than the change from elastic to plastic behaviour recorded by the yield stress and yield-point elongation. This suggests that the beginning and the end of the strain-ageing process have less effect on strain hardening than on yield-point phenomena.

As this paper has shown, it was only possible to make a rough estimate of the value of the yield stress immediately after temper rolling but this is sufficient to give a qualitative comparison between the return of the yield-point elongation and the increase in yield stress on ageing after temper rolling. Such a comparison is illustrated in Fig. 12 and suggests that the same basic mechanism operates when ageing temper-rolled steel as when ageing stretched steel, i.e. the increments in yield stress and hardness depend on the diffusion of carbon or nitrogen atoms to dislocations. This conclusion has also been reached independently by Hundy.[3] The quantitative equivalence of the amount of hardening produced by ageing after these two different methods of pre-straining was intentional, since the amounts of pre-strain were selected with this in mind.

The retardation of the return of the yield-point elongation by temper rolling when compared to pre-straining in tension appears to be connected solely with the propagation of the yield throughout the test piece and with the changeover from conditions of yielding to conditions of strain hardening. As temper-rolled steel, because of inhomogeneous deformation, contains internal stress it is not difficult to visualize the way in which the yield elongation is affected and a qualitative picture has been developed by Polakowski[2] and Hundy[3] along the following lines. The presence of such stresses, whether acting over macroscopic or microscopic dimensions, will initiate early yielding. Hence in the temper-rolled sheet yielding will not be sudden but will take place progressively at increasing applied stress values. As ageing proceeds a greater number of dislocations become anchored, and the effect of internal stress diminishes in a proportionate manner; but the absolute

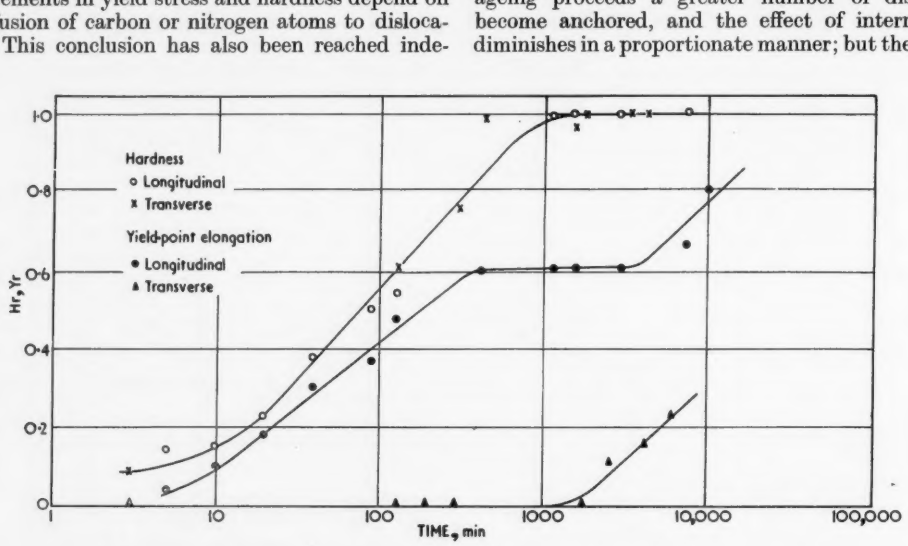


Fig. 14—Effect of direction of testing on rate of return of yield-point elongation

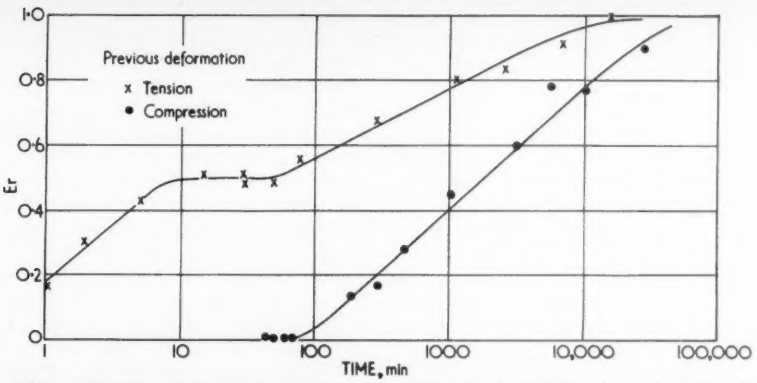


Fig. 16—Effect of mode of previous deformation on rate of return of yield-point elongation

value of the measured yield elongation is less than that measured on a stress-free test piece in which cataclysmic movement of dislocations may take place. This concept is illustrated in Fig. 13. Recently Hundy[3] has advanced the argument that to explain the observed differences in ageing between longitudinal and transverse test pieces cut from a temper-rolled sheet it is necessary to postulate that macro-stresses affect the return of the yield-point elongation of the longitudinal test pieces, whereas micro-stresses are more important in the lateral direction. The authors doubt whether this model holds when the results are considered quantitatively, and an attempt is made to claim that the observed differences in elongation at the yield point arise through differential yielding of grains. The masking effect is too great to be obtained by the individual yielding of microscopic portions since the neighbouring unyielded portions will, by elastic restraint, keep the total plastic flow to a small value. For reasons shown below the authors believe that the obscuring of the sharp yield point in the temper-rolled steel is due to oriented micro-stresses rather than body stresses, and it seems probable that they act by imposing a barrier to the movement of dislocations.

RETARDATION OF AGEING AFTER TEMPER-ROLLING

The above general mechanism has been suggested by Polakowski, who claimed that the operative internal stresses were macroscopic in nature. Further experiments were made to examine the question more closely. For these a Swedish pure iron supplied by B.I.S.R.A. was used which contained 0·05% C and 0·008% N together with other elements of which no single one was present in any greater amount than 0·02%. The general ageing characteristics were very similar to those found in the rimming steel, and in particular a step was found in the ageing curve when measured in terms of the yield elongation.

In pure tension there should be no appreciable body stresses left after straining. Therefore, if body stresses are important, there should be no distinction between the rate of return of the yield-point elongation in test pieces aged and tested in a direction transverse to the original direction of pre-straining and those re-tested in the same direction. This is contradicted by Fig. 14, which shows that the return of the yield-point elongation on ageing at 64·5° C is affected by the relation of the direction of testing to the direction of pre-straining. The considerable delay in observing a yield-point elongation with these transverse test pieces was similar in all respects to the delay after temper rolling (cf. Fig. 7). Figure 15 shows that the transverse test pieces if aged at a higher temperature showed a full curve with a horizontal step similar to Fig. 7. Further evidence that the Bauschinger effect

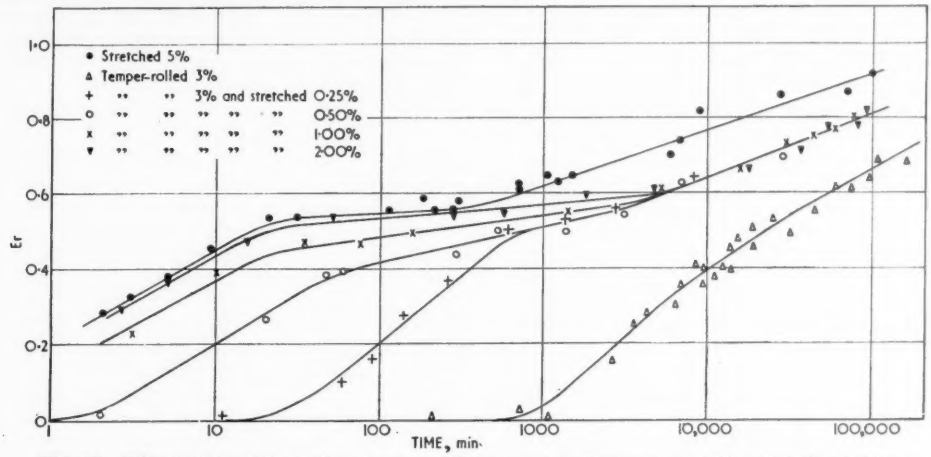


Fig. 17—Effect of stretching after temper rolling on rate of return of yield-point elongation

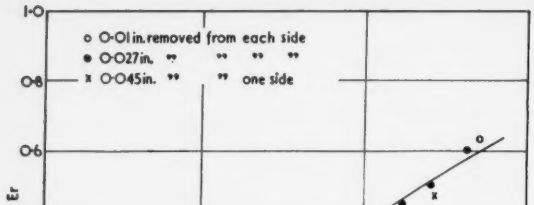


Fig. 18—Strain-ageing curves for deep-etched material

(i.e. the formation of oriented micro-stresses by straining) is more important than that of body stresses is presented in Fig. 16, which shows the considerable delay in the return of the yield elongation which occurred when test pieces were pre-strained in compression and re-tested in tension after ageing at 64·5° C.

If internal micro-stresses mask the return of the yield elongation on ageing, it should be possible to remove the delaying action of temper-rolling by reorienting the micro-stresses arising from rolling by stretching in tension before ageing. Such a procedure is successful as Fig. 17 shows and it was found that 2% extension was sufficient to restore the rapid return of a sharp yield point after the material had been temper-rolled with a 3% reduction. Similarly, it was found that if the temper-rolling reduction were given in two reversed passes, the elongation at the yield returned more quickly for a given set of ageing conditions. These results confirm those of Hundy, who found that the rate of ageing of temper-rolled sheet could be radically altered by roller-levelling.

It has often been shown that macro-stresses are present in a rolled sheet. If these are important, the deep etching of the surfaces of the sheet should have some effect on ageing since the removal of surface metal reduces the internal stress. Samples of sheet were rolled with a reduction of 3% to a final thickness of 0·070 in. and divided into three groups; one was etched down to 0·05 in. thickness by etching both faces, the second group was etched to 0·025 in. by etching one face only, and the final group was etched to 0·017 in. thickness by etching both faces. There were no differences in the yield elongations of these various groups after ageing at 64·5° C, as Fig. 18 shows.

The shape of the ageing curve when measured in terms of the yield-point elongation is very interesting but this work was not designed to examine it more closely. It might be thought that the apparent division of ageing into two stages for this mechanical property arose through segregation of foreign atoms in the lattice in the first stage[11] followed by precipitation. However, there do not appear to be the parallel changes in hardness and yield stress which such a process would show. Hence it may be that the increase in the yield elongation in the second stage is related to changes in the rate of strain hardening, i.e. to a shift in the basic stress/strain curve. This explanation can only be speculative until further work has been carried out. Figures 7, 12, and 14–18 show that the shape of this curve is apparently altered by temper-rolling as a method of pre-straining and a step is only obtained at the higher ageing temperatures. It seems likely that if the general explanation of retardation due to oriented micro-stresses is correct, the step is not observed when the ageing conditions are such that only a fraction of the yield elongation has returned.

Cottrell and Bilby[5] have shown theoretically that strain ageing is governed by the transference of solute atoms to dislocations. Hundy[12] has modified their equation to the form:

$$\log_{10}\frac{tr}{t} = 4400\left(\frac{1}{Tr} - \frac{1}{T}\right) - \log_{10}\frac{T}{Tr}$$

where tr is the strain-ageing time at room temperature Tr, and t is the time to give a similar degree of ageing at an elevated temperature T, the temperatures being expressed in °K.

Since the results reported in this paper confirm the belief that the activation energy for the process is that for the diffusion of carbon and/or nitrogen in α-iron it is not surprising that this equation proves to be accurate when applied to the changes in yield stress and hardness which have been discussed. However, Figs. 6 and 7 show that whenever the circumstances of ageing are such that the step in the return of the yield-point elongation curve is involved, the equation may be badly misleading. Fortunately from the industrial point of view, the duration of the step was less in the temper-rolled test pieces than in those which were pre-strained in tension. Hence the results suggest that if the artificial ageing temperature is below 100° C, or if a comparison is made between ageing times which give over 75% of the annealed yield-point elongation, a more accurate estimation may be obtained.

CONCLUSIONS

(1) The change in lower yield stress, yield elongation, and hardness have all been used to follow the ageing process after low-carbon steel was pre-strained by rolling and by stretching in tension. The measured values of the activation energies for the process agreed closely whatever the criterion of ageing, so leading to the conclusion that the method of pre-straining does not affect the basic mechanism of strain ageing.

(2) The beginning and end of the strain-ageing process cannot be measured in terms of any single mechanical property. Changes in the yield stress and elongation occur both before and after the changes in hardness have occurred. It is suggested that this indicates that the beginning and end of the strain-ageing process have a greater effect on yield-point phenomena than on subsequent strain hardening.

(3) The apparent retardation of ageing caused by temper-rolling as compared with stretching appears to be confined to the yield-point elongation. It is suggested that this is due to the pattern of oriented micro-stresses imposed by the method of pre-straining, since unless the direction of testing after ageing is the

same as that of pre-straining, the early stages of the return of the yield-point elongation are obscured. The results indicate that the influence of body stresses may be of a minor character.

(4) It is suggested that the return of the yield-point elongation on ageing may be a two-stage process.

Acknowledgments

This work was carried out whilst the authors were members of the Department of Industrial Metallurgy of Birmingham University, and they would like to express their appreciation of the laboratory facilities put at their disposal by Professor A. J. Murphy. One of the authors (H.P.T.) would also like to thank the Athlone Fellowship Committee for financial support. Further debts are acknowledged to their colleagues for many helpful discussions.

References

1. R. KENYON and R. S. BURNS: *Transactions of the American Society for Steel Treating*, 1933, vol. 21, pp. 577–601.
2. N. H. POLAKOWSKI: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 369–376.
3. B. B. HUNDY: *Ibid.*, 1954, vol. 178, pp. 127–138.
4. C. F. TIPPER: *Ibid.*, 1952, vol. 172, pp. 143–148.
5. A. H. COTTRELL and B. A. BILBY: *Proc. Phys. Soc.*, 1949, vol. 62, ser. A, pp. 49–62.
6. E. S. DAVENPORT and E. C. BAIN: *Trans. Amer. Soc. Metals*, 1935, vol. 23, pp. 1047–1052.
7. A. H. COTTRELL and A. T. CHURCHMAN: *J. Iron Steel Inst.*, 1949, vol. 162, pp. 271–276.
8. S. HARPER: *Phys. Rev.*, 1951, vol. 83, pp. 709–712.
9. A. H. COTTRELL and G. M. LEAK: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 301–306.
10. G. WELTER: *Metallurgia*, 1936, vol. 13, pp. 183–187.
11. A. H. COTTRELL and G. M. LEAK: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 344–347.
12. B. B. HUNDY: *Ibid.*, 1954, vol. 178, pp. 34–38.

Correspondence on the Paper—

The State of the Carbon in Austenite and Martensite as Revealed by the Eggertz Test *

By F. C. THOMPSON and A. R. CHAUDHURI

Mr. **Floyd Brown** (Naval Research Laboratory, Washington, U.S.A.) wrote: The authors interpret their colorimetry data (on steels dissolved in nitric acid) as evidence that the carbon in austenite is partly present in some form of chemical combination and partly dissolved in the elementary state, a concept which if true would have important implications to hardenability theory and as such would justify particularly careful consideration of the experiment. Bearing in mind especially the far from complete understanding of the colour-forming reaction between acid and steel, the intensity of which colour serves as the primary measure upon which the authors' conclusions are based, it is suggested here that a more conservative interpretation is compatible with the authors' data.

The carbon in martensite is only two-thirds to three-fourths as effective as that in cementite for producing the colour complex, and the carbon in both these is far more effective at this than is graphite. It is suggested therefore that the carbon in austenite reacts differently to the acid from that in either martensite or cementite. (Neither the data of the original paper nor those to be given below are out of line with the conclusion that carbon in retained austenite contributes very little indeed to the colour.) The effects observed in Figs. 2 and 3 can then be interpreted as reflecting simply a rise in retained austenite as the austenitizing time, the austenitizing temperature, and the carbon content are increased (all three of which changing conditions are commonly known to lower M_f).

As a test of the retained-austenite interpretation, specimens of high-carbon unalloyed steel (approx. 1·05% C) were austenitized in dried helium at two temperatures (838° and 950° C) for 30 min and water-quenched, and two specimens from each such treatment were further cooled in liquid nitrogen. The colour intensity values (colour-photometric) from these specimens are shown in Table *A*. These intensity data have been reduced to " per cent carbon " by a calibration graph similar to that of Fig. 1.

Here it is seen that the liquid-nitrogen treatment, which induced additional transformation of retained austenite to martensite, occasioned a substantial increase in the intensity of colour, which is difficult to rationalize otherwise than that the carbon in retained austenite does not produce as much colour in the acid solution as that in martensite.

Table A

Treatment	Colour Intensity (as " % carbon ") Individual Values	Average	Hardness R_C (average)
Austenitized ½ h at 838° C, W.Q.	0·72, 0·72	0·72	67·0
Austenitized ½ h at 838° C, W.Q., liq. N_2	0·79, 0·82	0·80	67·7
Austenitized ½ h at 950° C, W.Q.	0·66, 0·56	0·61	61·4
Austenitized ½ h at 950° C, W.Q., liq. N_2	0·69, 0·63	0·66	66·2

The " curious bulge " of Fig. 6, incidentally, is reasonably interpretable as reflecting differing effectiveness of carbon when it is (i) changing the *amount* of martensite compared with the situation when it is (ii) changing the *composition* of the martensite. For the limits of the bulge in each curve correspond to the crossing of A_3 and A_{cm}.

The basic data of the original paper are thus considered rationalized in terms of current concepts without supporting (or denying) the existence of the postulated compound-like associations of carbon in austenite.

AUTHORS' REPLY

Professor **F. C. Thompson** (Manchester University) wrote in reply: There does not appear to be much real difference between the views of Mr. Floyd Brown and ourselves. He and we alike are in agreement with the fact, which has really been known for a very long time, that the colour developed from martensite or austenite is less intense than that from an annealed steel of the same carbon content.

Whereas, however, we have offered an explanation, rightly or wrongly, of the effect, Mr. Floyd Brown merely accepts the fact. There must, however, be some explanation of the difference, and our own is in the present state of knowledge, we believe, the most probable.

* *J. Iron Steel Inst.*, 1954, vol. 178, Sept., pp. 44–50.

Sub-structures in Ferrite

By P. Samuel and A. G. Quarrell

SYNOPSIS

Investigation of α-veining phenomena in ferrite has shown that the veining networks represent the boundary regions between crystal blocks of slightly dissimilar orientation within each grain. These sub-boundaries are only clearly revealed when impurities are concentrated along them. The important impurities for this effect are believed to be carbon and possibly nitrogen. Sub-structures in other metals and alloys may be explained on a similar basis.

Gamma-ghost boundaries, which appear only in rapidly cooled iron, are attributed to the segregation of an impurity along the grain boundaries of the metal when in the γ state.

The appearance of the α-grain boundaries as ridges in etched microsections of Armco iron is believed to be brought about by carbon segregation; the ridging effect may be destroyed in several ways, including decarburization or recrystallization in the α range.

1079

Introduction

SINCE THE FIRST report of a sub-crystalline structure was made 60 years ago,[1] sub-structural details have been observed in many metals and alloys. In iron these phenomena have been of four main types:

(i) The δ network [2,3] due to the segregation of minute inclusions along what had been the δ-grain boundaries

(ii) The γ networks,[2–5] which represent the grain-boundary structure of the former γ phase

(iii) A diffuse band network associated with phosphorus segregation[6–7]

(iv) Alpha-veining networks.[1, 2, 7–25]

Some confusion between these various phenomena appears to exist in the literature. Alpha-veining appears to be the only truly sub-crystalline structure for, unlike the others, the networks are confined within each ferrite grain by the grain boundaries. The present work was undertaken in an attempt to explain the α-veining phenomena in iron, to determine the conditions under which it appears, and as far as possible to remove the confusion with other phenomena. Some of the observations made throw light upon the nature of the γ networks and the α-grain boundaries.

Metallographic and X-ray studies were made on Armco iron and a number of pure iron–oxygen alloys of known oxygen and carbon contents after a variety of heat-treatments. These treatments were chosen to reveal the conditions under which α-veining may be produced or eliminated and also to check some of the conflicting statements made in the literature.

Manuscript received 19th July, 1954.

Dr. Samuel is Senior Lecturer in Metallurgy in the Sheffield College of Commerce and Technology, and Dr. Quarrell is Professor of Metallurgy in the University of Sheffield.

MATERIALS EXAMINED

Most of the experiments were made on Armco iron available as $\frac{5}{8}$-in. dia. hot-rolled rod. Later, small amounts of low-carbon iron–oxygen alloys of known composition became available.* The analyses are given in Table I.

EXPERIMENTAL PROCEDURE

Treatments were given in a small furnace whose atmosphere could be controlled. All the high-purity irons and some specimens of the Armco iron were heat-treated *in vacuo* at pressures of better than 10^{-4} mm Hg; others were treated in air or hydrogen.

Alpha-veining networks are revealed inside the

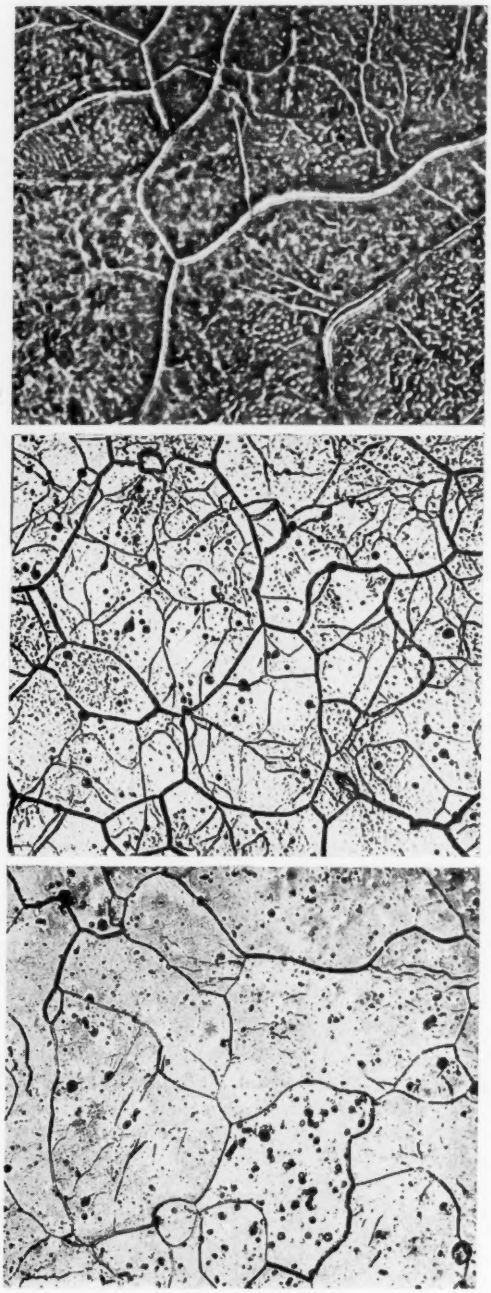
* Through the courtesy of Dr. N. P. Allen, Metallurgy Division, National Physical Laboratory, and Dr. M. L. Becker, Metallurgy (General) Division, British Iron and Steel Research Association.

Table I

ANALYSES OF IRONS STUDIED

	C, %	Si, %	Mn, %	S, %	P, %	Al, %	N, %	O, %
Armco iron	0·035	tr.	0·08	0·04	0·01	0·05	0·007	n.d.
N.P.L. 53AF1	0·0025	0·003	0·005	0·0046	0·001	0·004	0·001	0·001
N.P.L. 47AF1	0·003	0·001	n.d.	0·0031	n.d.	0·001	0·003	0·057
N.P.L. 46AF2	0·0044	0·001	0·005	0·0038	0·001	0·001	0·010	0·270
B.I.S.R.A. 33AHR7	0·001	0·001	n.d.	0·0067	n.d.	0·001	0·002	0·006

normal grain boundaries by prolonged etching, and a scratch-free surface is desirable if they are to be seen clearly. In view of difficulties encountered in obtaining a satisfactory polish by mechanical means, electrolytic polishing in an acetic–perchloric acid bath was adopted.[26] With the optimum polishing conditions, pitting and etching could be minimized but never eliminated. From the examination of the N.P.L. and B.I.S.R.A. irons it appeared that the amount of pitting was directly related to the oxygen content.



(a) As-received. Etched 4 min in saturated picral × 900
(b) Annealed 950° C. Etched 2 min in saturated picral × 200
(c) Quenched from 800° C. Etched 15 min in nital–picral mixture × 200

Fig. 1—Alpha-veining in Armco iron

Although many etchants have been recommended for the study of α-veining, only nital and saturated picral or combinations of the two were found satisfactory. Of these picral was preferred since it was slower in action and revealed fine detail without excessive coarsening. Nital attack tended to be preferential on certain grains, and gave a ' weighted ' representation of α-veining.

The condition of the specimen had an effect on the clarity of the α-veining—e.g. a furnace-cooled specimen etched more readily in a given time than one air-cooled or quenched. In general, veining became just visible after 30 s in saturated picral at room temperature, though for ease of observation it was often necessary to etch for as long as 4 min.

Etching in a solution of 2% nital, containing about 2% saturated picral, for an optimum time of 15 min revealed traces of α-veining in some of the specimens that would otherwise have been classified as vein-free if etched only in picral or nital (*see* Fig. 1*c*). Specimens are described in this paper as vein-free only if they appeared so even when etched in the nital–picral mixture; the α-veining is described as fully developed if it was visible within most grains after etching in picral. Where it is stated that normal veining has been eliminated, traces may or may not have been visible after deep-etching, but the context will make this clear.

EXPERIMENTAL RESULTS

A summary of the more important results of the heat-treatment of Armco iron, initially in the as-received condition, is given in Table II.

As-Received, Annealed, and Normalized Structures

Typical structures of the Armco iron are shown in Figs. 1*a* and *b*. The general mottling, suggestive of precipitation, was observed in all slowly cooled specimens. Step-wise widening of the grain boundaries caused by the relatively deep etch resulted in the appearance, under the microscope, of double and even treble boundary lines. It was generally true of all specimens that grain boundaries showed little change in direction when intersected by veins; in addition, veins ended in grain boundaries and did not cross them. The depth of focus of the microscope was sufficiently great at about 200 diameters to allow the veins to be photographed either as black or white lines at will. At high magnifications the depth of focus was insufficient for this and the veins showed up only as white lines, suggesting that they were surface ridges (*see* Fig. 1*a*). The techniques of phase-contrast and electron microscopy confirmed this and showed that the ridges were almost completely continuous up to the limits of resolution.

Little effect on the general appearance of the α-veining networks was produced by various annealing or normalizing treatments from the γ range, though normalizing reduced the ease of etching and preserved remnants of the γ boundaries.

Table II
SUMMARY OF RESULTS OF HEAT-TREATMENT

Treatment	Sub-Structure Revealed by Normal Picral Etch	Sub-Structure Revealed by Deep Nital–Picral Etch
1. As-received	Well-defined α-veining networks (Fig. 1*a*)	...*
2. Annealing within γ-range	Fully developed α-veining networks: i.e. more prominent than in 1 (Fig. 1*b*)	...
3. Normalizing from γ-range	Well defined α-veining networks. Remnants of γ-boundaries	...
4. Heat-treatment in α-range		
Range (*a*) 850–700° C		
(i) Water-quenched	None	Traces of α-veining within some grains (Fig. 1*c*)
(ii) Slowly cooled	Well developed α-veining networks	...
Range (*b*) 700° C–room temp. Water-quenched or slowly cooled	Well developed α-veining networks	...
5. Tempering water-quenched specimens from 4 (*a*) (i)		
Range (*a*) Room temp.–400° C, then slow-cooled or water-quenched	Strings of particles resembling α-veining in some grains to an extent depending on temperature and length of treatment	...
Range (*b*) 400–650° C, then slow-cooled or water-quenched	Well defined α-veining networks according to temperature and length of heat-treatment	...
6. Water-quenching from γ-range	γ-boundaries, striated and distorted α-grains (Figs. 2*a–c*)	...
7. Water-quenched from 1000° C (*see* 6) and tempered for 2 h		
Range (*a*) Room temp.–400° C	The structure of γ-boundaries, striated and distorted α-grains persists	...
Range (*b*) 400–650° C	Well defined α-veining networks depending on temperature and length of treatment	...
8. (*a*) Annealing within γ-range in dry hydrogen	Fully developed α-veining networks	...
(*b*) Decarburization in moist hydrogen 21 days at 860° C and furnace-cooled	None	Traces of α-veining within some grains
(*c*) Re-annealing of specimens (from 8*b*) within γ-range	None	Traces of α-veining within some grains
9. Equilibrium annealing for 400 h at 850° C	Well developed α-veining networks	...
10. (*a*) Recrystallization in α-range	None, after complete recrystallization	None, after complete recrystallization
(*b*) Re-annealing recrystallized specimens (from 10*a*) within γ-range	Fully developed α-veining networks	...

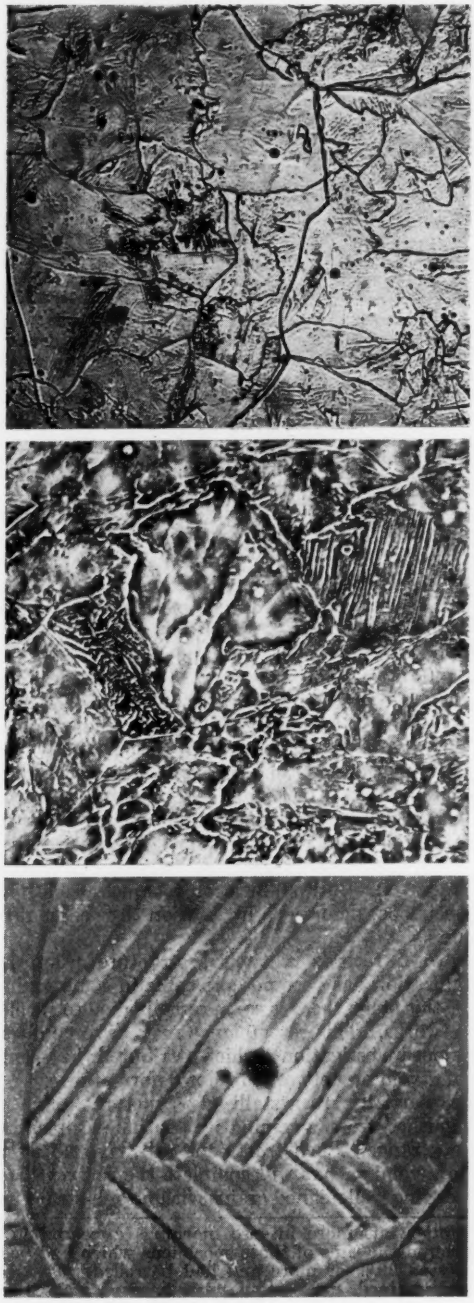
* Throughout the work representative specimens were examined after deep etching, but no advantage was gained if a sub-structure was revealed by the normal etch. The general severe over-etching caused confusion and in the specimens of 6 and 7*a* it was not possible to decide whether traces of α-veining existed or not.

Vacuum etching was used to detect any possible relationship that the α-veining networks might have to previously existing grain structures. A typical sequence of micrographs, from the same area of a specimen, are given in Figs. 3*a–c*. Figure 3*a* records the α-grain structure before transformation; the structure after transformation is shown in Fig. 3*b*, with the γ and previous α-grain structures superimposed on the α boundaries. A light repolish and etch (Fig. 3*c*) distinguished the new α grains and the α-veining networks, leaving the ghost lines of the former γ boundaries. Obviously, α-veining networks are related only to the newly formed α grains.

Elimination and Production of Normal Alpha-Veining

The results reported in Section 4 of Table II show that normal α-veining networks can be eliminated by water-quenching after holding at a temperature within the range 700–850° C, but that the veining persists if the iron is slowly cooled from this range or if the heat-treatment is below 700° C. On quenching from 700° C, normal veining was eliminated with a holding time of 1 hr. or more, but it persisted with shorter heat-treatment times. Results similar to those in Section 4 of Table II were also obtained in specimens that had been annealed in the γ range before heat-treatment.

In specimens which had been freed from normal α-veining by quenching from the range 850–700° C, veining reappeared progressively on tempering at temperatures up to 650° C (*see* Section 5 of Table II).



(a)

(b)

(c)

(*a*) Armco iron quenched from 950° C × 200
(*b*) Iron 33*ARH*7 quenched from 950° C × 300
(*c*) As (*b*), electron micrograph, Formvar negative replica × 3800

Fig. 2—Gamma-networks and quenched alpha structure. All etched 2 min in saturated picral

Below 400° C the veining was discontinuous; at higher temperature it was normal in appearance.

No α-veining networks were found in specimens water-quenched from the γ range, but well defined γ boundaries were observed superimposed on the ferrite structure, which contained numerous striations and markings (*see* Figs. 2*a* and *b*). The rumpled appearance of the surface (*see also* Fig. 2*c*) suggested that plastic deformation had occurred, but these specimens had been sectioned, polished, and etched after treatment. Similar markings could be preserved on the polished surface of specimens cooled quickly *in vacuo* from the γ range and have been obtained on quenching low-carbon irons after vacuum treatments in the γ range.[27, 28] Their detection by normal metallographic techniques indicates that the distortion is not confined to the free surface. Slip lines revealed by etching deformed α-brass have been attributed to non-uniform deformation,[29, 30] an argument which may also apply to quenched iron.

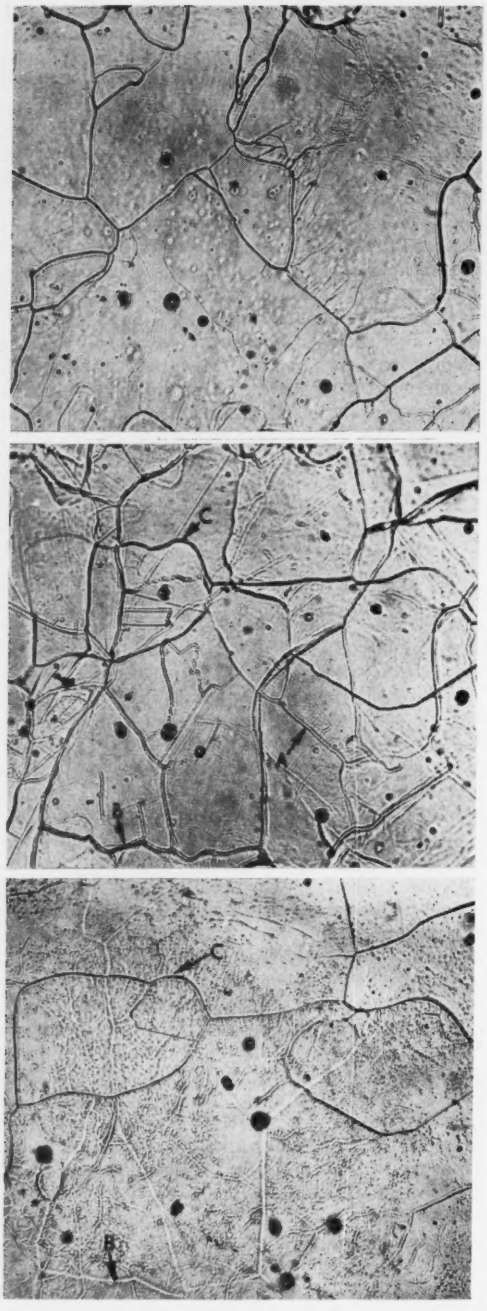
This structure, as observed in specimens quenched from 1000° C, persisted on tempering for 2 h at temperatures up to 400° C, but was gradually replaced by normal α-veining as the tempering temperature was raised towards 700° C (*see* Sections 6 and 7 of Table II).

Annealing in hydrogen has been reported by some workers to increase the clarity of α-veining networks[7] and by others to eliminate them.[17] Observations in the present work suggested that both claims might be correct, since the condition of the hydrogen was found to be important (*see* Section 8 of Table II). For instance, treatments in dry hydrogen for 13 days at 1350° C or up to 28 days at 1000° C did not appreciably diminish the intensity of the α-veining networks, though after such treatments the metal had a larger grain size and was cleaner microscopically. On the other hand, a decarburization treatment of 21 days at 860° C in an atmosphere of moist hydrogen produced material which was free from normal α-veining, although the specimens had been furnace-cooled. The same result obtained on examination after reheating into the γ range and furnace-cooling.

It has been shown that ideally the grain boundaries of an annealed polycrystalline single-phase metal should make angles of 120° with each other at their intersections as a result of the balance of surface energies.[31] Thus, given sufficient mobility, the grain boundaries in iron should approach their equilibrium positions and the veining networks, if due to non-equilibrium conditions, should disappear. This was studied by annealing Armco iron specimens for 400 h at 850° C or by slowly cooling at 4, 15, or 60° C/h through the $\gamma \rightarrow \alpha$ transformation and down to 650° C before water-quenching. Although regular polyhedral grains with equi-angular grain-boundary junctions resulted, fully developed α-veining networks were also present, a result which disagrees with previous work.[24]

Effect of Recrystallization in the Alpha-Range

In the experiments described above, water-quenching from the range 850–700° C or soaking in moist hydrogen at 860° C freed the Armco iron from normal α-veining, but after each treatment traces of α-veining



(*a*) α-grain boundaries and some α-veining after vacuum-etching ½ h at 850° C

(*b*) Same area as (*a*) after subsequent vacuum-etching for ½ h at 950° C. *A* = former α-grain boundaries; *B* = γ-grain boundaries; *C* = new α-grain boundaries

(*c*) Same area as (*a*) after light repolish and etch of 4 min in saturated picral. *B* = γ-grain boundaries; *C* = α-grain boundaries and α-veining

Fig. 3—Surface changes caused by the $\alpha \rightarrow \gamma$ transformation in an Armco iron specimen. In each case specimen cooled by removal of furnace from vacuum tube × 300

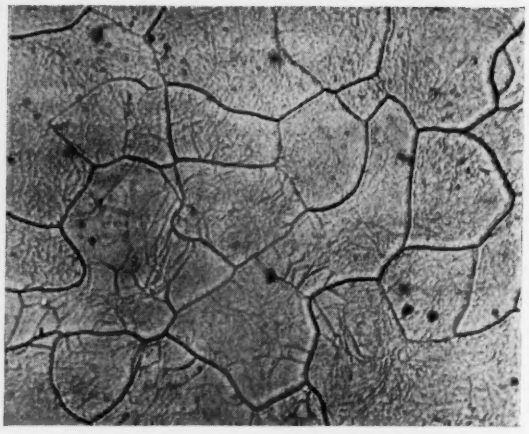


Fig. 4—Armco iron specimen soaked 2 h at 800° C and W.Q. after 10% reduction in height by cold compression. Etched 2 min in saturated picral × 500

were detected in some grains by the use of the deep nital–picral etch. In other words, none of these treatments was completely successful in removing α-veining. Another treatment that has been reported[13,16] as destroying α-veining is recrystallization in the α range. Further experiments were therefore made to see how effective this treatment might be.

Specimens 15 mm dia. × 15 mm long were compressed to give reductions in height of 10–66%. After compression, the specimens were sectioned and heat-treated in the range 600–850° C and prepared for micro-examination.

Each grain in the compressed state contained profuse, fine, and approximately parallel markings,* none of which appeared to cross the grain boundaries. As annealing progressed, new grains formed and grew within the old structure until only a new grain-boundary structure existed. No α-veining networks were observed in any of these specimens after recrystallization, and no traces were detected by prolonged etching in the nital–picral reagent (*see* Section 10*a*, Table II). Recrystallization was just as effective in specimens deformed in tension by equivalent amounts.

Figure 4 records a typical structure when recrystallization has become noticeable in some grains, and at this stage there is some resemblance to α-veining networks. This resemblance may have confused a previous investigation[24] which attributed the formation of α-veining networks to hot deformation.

The partially recrystallized structure may be distinguished from α-veining by continued annealing in the α range. Such treatment will have no effect on the α-veining, but will complete the recrystallization, leaving well defined grains with no sub-structure.

* Similar but more intense markings appeared in a band round the rims of those specimens which had been compressed 20% or more and had barrelled. The rim zones remained proportionately harder and more resistant to recrystallization compared with the centres of the specimens. The effect varied with the degree of barrelling and was never present in specimens deformed in tension. It is suggested that polygonization had occurred in these regions as a result of the non-uniform deformation.

(a) Normal α-veining
(b) Traces of α-veining on deep etching
(c) Completely recrystallized, no α-veining

Fig. 5—X-ray diffraction patterns

Alternatively, the two structures may be distinguished after quenching from the range 700–850° C when the partially recrystallized structures, consisting solely of grain boundaries, will still be readily visible to a picral etch whilst the α-veining will not be observed (*see* Section 4*a*, Table II).

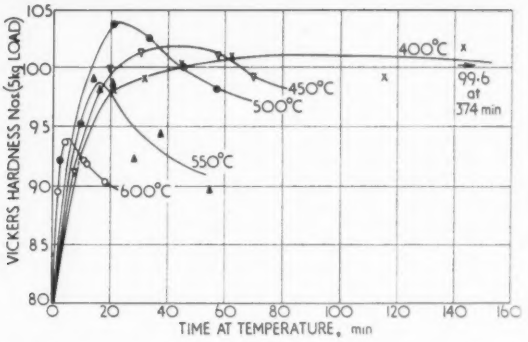


Fig. 6—Change of hardness with time on tempering specimens of Armco iron, quenched from 800° C, in the 400–600° C range

No heat-treatment in the α range was found which would develop α-veining in fully recrystallized specimens; on the other hand, veining reappeared immediately on heating into the γ range and recooling (*see* Section 10*b*, Table II).

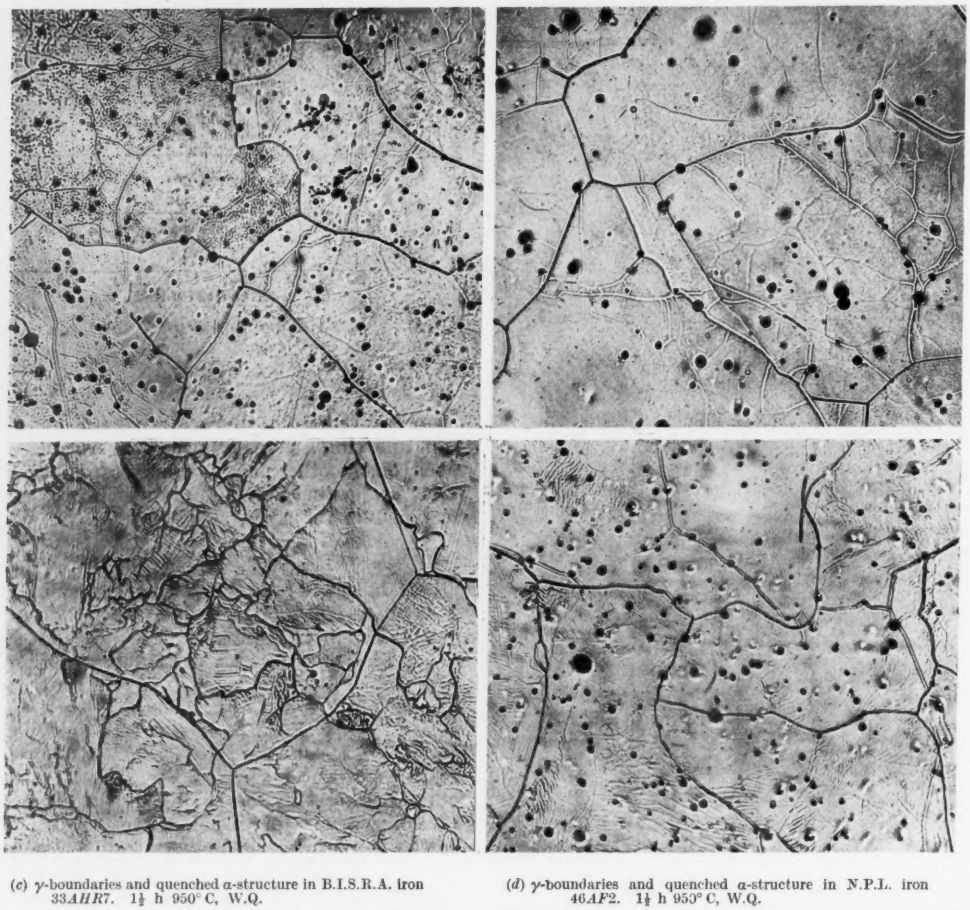
Examination by X-ray Diffraction

Certain micro-specimens were examined by the X-ray back-reflection technique using cobalt radiation and an iron filter; similar methods had been found to reveal the presence of sub-structures in iron.[23, 32] Although it was not possible to show exact correspondence of the X-ray pattern with the microstructure, the X-ray evidence for the presence or absence of a sub-structure agreed with the metallographic evidence. The X-ray diffraction patterns obtained, however, were similar for specimens in which α-veining was readily visible microscopically (*see* Fig. 5*a*) to those in which only traces showed up after deep etching (*see* Fig. 5*b*). In each case every diffraction spot consisted of a closely grouped cluster, indicating that there were a number of crystal blocks of slightly differing orientations within each grain. When recrystallized specimens were examined, a larger number of spots appeared, owing to the grain refinement, but the spots were not sub-divided (*see* Fig. 5*c*). This indicated the absence of a sub-structure, in agreement with the metallographic evidence.

Effect of Alpha-Veining upon Hardness

Specimens which had been freed from normal α-veining (*see* Section 4*a*, Table II) were individually tempered at various temperatures, the progress of tempering being followed by hardness determinations and microscopic examination. The hardness curves, corrected for initial differences, are reproduced in Fig. 6, each point representing an average of five readings. The changes occurring on tempering resemble in many respects those of a quench-ageing process. As with normal quench-ageing, tempering produced a rapid increase in hardness to a maximum followed by a gradual decrease to a lower steady value. Also, the magnitude of the peak and the time at which it appeared varied with temperature. At temperatures below 400° C hardening was very slow, and the condition of maximum hardness was not

(*a*) α-veining in N.P.L. iron 46*AF*2. Annealed 1 h at 950° C (*b*) α-veining in N.P.L. iron 47*AF*1. Annealed 1 h at 950° C



(*c*) γ-boundaries and quenched α-structure in B.I.S.R.A. iron 33*AHR*7. 1½ h 950° C, W.Q. (*d*) γ-boundaries and quenched α-structure in N.P.L. iron 46*AF*2. 1½ h 950° C, W.Q.

Fig. 7—Iron–oxygen alloys, etched 2 min in saturated picral × 300

reached in the times for which observation was continued. In these specimens, micro-examination revealed the development of strings of particles rather than the usual α-veining lines; similar observations have been made recently.[33, 34]

Traces of the veining could be detected in the as-quenched condition by the nital–picral etch, but as tempering proceeded, at temperatures of 400° C and above, similar traces could be observed after picral etching alone. It was not until after the hardness peaks had been passed that well defined α-veining networks were observed.

Experiments were made to determine how the mechanical properties were affected by the changes produced by tempering. Unfortunately the supply of the original Armco iron ran out and tests had to be made on a limited amount of ingot iron of similar composition, after tests had indicated that this material closely resembled Armco iron so far as α-veining phenomena were concerned. Small bars were quenched, tempered at 500° C for 15, 25, 40, or 60 min, machined into $\frac{1}{20}$-in^2 cross-sectional area standard tensile specimens, and tested.

Well defined α-veining networks were observed at the same stage as with the Armco iron (i.e. after 25 min tempering treatment), and the hardness varied in a similar way but within a narrower range and at a rather higher level, changing from 93 to 110 D.P.N. at the maximum and falling to 106 D.P.N. after the 60-min treatment. Tempering at 500° C for 60 min caused the following changes in mechanical properties:

Yield point decreased from 13 to 10 tons/in^2
Maximum stress decreased from 22 to 21 tons/in^2
Elongation increased from 35% to 55%
Reduction in area increased from 55% to 61%.

The greatest changes occurred during the first 15 min of tempering.

These results suggested that the mechanical properties were not very sensitive to changes in veining caused by the ageing treatment. It may well be that the tempering temperature, chosen from the Armco iron results, was not the optimum for the ingot iron; certainly the changes in hardness were much smaller.

Examination of N.P.L. and B.I.S.R.A. Irons

Samples, whose analyses are given in Table I, were received in the normalized condition from these sources. It was hoped that the variations in purity of these irons would give some indication of the element responsible for outlining the sub-boundaries but their behaviour was exactly that of Armco iron (Figs. 7*a–d*) with reference to α-veining networks. Striated α grains with γ-ghost boundaries were detected in these specimens when quenched from the γ range.

DISCUSSION

The Nature of Alpha-Veining

The results given show that α-veining is a stable feature of the structure of low-carbon irons. The heat-treatments described in Sections 4*a* (i) and 8*b* of Table II cause the disappearance of the α-veining features previously revealed by the normal picral etch, but even after these treatments traces of α-veining were shown up by deep etching. Moreover, the X-ray evidence indicated that whether a fully developed α-veining network existed or just traces that could only be revealed by deep etching, each ferrite grain consisted of a number of crystal blocks of slightly different orientations. The metallographic and X-ray results can be reconciled if it is accepted that

(i) The traces of α-veining reported in the last column of Table II are shown up because the nital–picral reagent attacks the boundaries between adjacent crystal blocks when there is a relatively large orientation difference between them, and
(ii) Well defined α-veining is shown up by the picral etch when impurity atoms have concentrated along the sub-boundaries.

Comparison of the results in Sections 4 and 5 of Table II suggests that the effect of treatment in the range 850–700° C followed by water-quenching is to even out the concentrations of impurity elements which, however, can re-form if the quenched specimens are tempered or if cooling from 850–700° C is slow. On the other hand, treatment in moist hydrogen at 860° C appears to remove the impurity elements responsible for preferential attack of the sub-structure boundaries by the picral etch, for normal veining was not observed after furnace cooling from 860° C or after reheating into the γ range. Both these treatments produce well defined veining in specimens which have not been heated in moist hydrogen.

The only method that has been found to remove all traces of α-veining, even when nital–picral is used, consists of complete recrystallization in the α range. On the argument advanced above, this must mean that the recrystallization has removed not the impurity, but the orientation differences between the crystal blocks of the ferrite. This would, indeed, be expected, for small-angle boundaries can be regarded as consisting of arrays of dislocations[35] and the effect of recrystallization would be to destroy the arrays and to sweep most of the dislocations to the new grain boundaries.*

Fully developed α-veining reappeared when recrystallized ferrite was heated to the γ range and slowly cooled. To have this effect the heat-treatment must have

(i) Restored the sub-structure of crystal blocks of slightly differing orientations within the ferrite grains, and
(ii) Allowed the impurity elements to concentrate along the sub-boundaries.

It seems likely that the sub-structure in ferrite is due to the deformation caused by the expansion associated with the $\gamma \rightarrow \alpha$ transformation[38] and that this deformation is rapidly followed by polygonization, i.e. the movement of dislocations into arrays. As mentioned earlier, the appearance of samples quenched from the γ range suggests that plastic deformation has occurred but, because of the rapid cooling, there has not been time for α-veining to be produced.

The Nature of the Alpha-Veining Impurities

In the preceding discussion it has been deduced that a concentration of impurities along pre-existing sub-boundaries is necessary before normal α-veining can be detected in ferrite. No particular impurity has yet been mentioned, but the evidence available for its identification may now be summarized as follows:

(i) The rate of cooling had an influence on the definition of the α-veining: the slower the cooling from temperatures above 700° C, the greater the etching speed
(ii) The responsible impurities were not concentrated along the sub-boundaries at 700° C and above (e.g. Section 4*a* of Table II)
(iii) The impurities concentrated at the sub-boundaries during tempering in the range 400–650° C. This process involved a calculated† activation energy of 18 kcal per g. atom.
(iv) Efficient decarburization (21 days in moist hydrogen at 860° C) completely prevented the detection of normal α-veining even in slowly cooled material and must therefore have removed the responsible impurity. It is reported that α-veining in 25% Cr ferrite is eliminated by decarburization and restored by the addition of 0·04% of carbon[25]
(v) Veining appears to be independent of composition of the iron within the ranges 0·001–0·27% oxygen, 0·001–0·10% nitrogen, and 0·001–0·35% carbon.

A consideration of these points together with the analyses given in Table I suggests that carbon, nitrogen, and possibly oxygen are the elements most likely to be responsible for the observed effects. Oxygen, unlike carbon or nitrogen, does not favour interstitial solution and its activation energy for diffusion should be much higher than that for carbon and nitrogen. The activation energy, calculated for the reappearance of α-veining networks, and the effect of decarburization are consistent with the view that carbon and possibly nitrogen are the impurities which concentrate at the sub-boundaries to cause α-veining.

The Restoration of Alpha-Veining by High-Temperature Ageing

There are many points of similarity between the process to which α-veining has been attributed above

* Experimental confirmation of this conception of small-angle boundaries and particularly that the boundary angle varies inversely with the distance between dislocations in the array has been obtained from measurements of etch-pit arrays within grains of high-purity aluminium.[35, 36]

† Derived from the hardness/tempering-time curves.

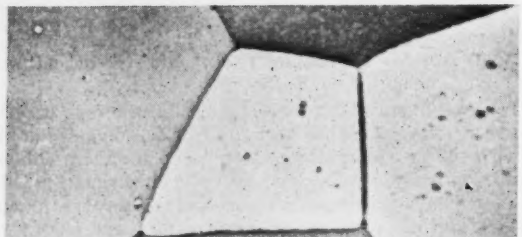


Fig. 8—Grooved α-grain boundaries in Armco iron recrystallized at 850° C after 60% reduction in height by compression. Etched 2 min in saturated picral. Formvar negative replica × 3800

and that of quench-ageing. Moreover, the curves relating hardness to tempering time (Fig. 6) are similar in shape to ordinary quench-ageing curves. A quantitative comparison of Fig. 6 with the quench-ageing curves of Davenport and Bain[39] reveals a large difference in the rates of the ageing processes, particularly when due allowance is made for the differences in temperature. This must mean that in the present case either some element other than carbon or nitrogen is responsible or else a different mechanism is operating. Put another way, it takes longer to restore normal α-veining than would be expected if the rate-controlling process were the diffusion of carbon or nitrogen atoms from the matrix in the immediate vicinity of the sub-boundaries. Yet the X-ray evidence indicates that the specimens freed from normal α-veining by quenching from 800° C, and which were used for the ageing experiments, already contained a well-developed sub-structure, traces of which were also revealed by the deep etch. Thus the tempering process was only responsible for bringing about the concentration of impurities along existing sub-boundaries. The reason why this should take longer than would be expected for the diffusion of carbon or nitrogen to the dislocation arrays that constitute the sub-boundaries is not understood. It is conceivable that the relative slowness with which the normal α-veining is restored may be due to the carbon or nitrogen being highly segregated at temperatures above 700° C so that the diffusing atoms have greater distances to travel to the sub-boundaries. The work of Menter, Nutting, and Tsou[40] and of Spretnak and Speiser[41] support the view that there is a tendency for carbon to concentrate at grain boundaries at higher temperatures, and such an explanation would account for α-boundaries occurring as ridges in the present work (*see* p. 29).

Veining in Other Metals

On the explanation given above, veining is likely to be observed in any metal containing sufficient dislocations to form sub-boundaries and sufficient impurity atoms. With iron the $\gamma \rightarrow \alpha$ transformation acts as a source of dislocations, and a sufficient impurity content is usually present. In the absence of transformations the dislocation source is less definite and the appearance of veining is likely to depend much more upon the mechanical history of the metal. Sub-boundary structures have been recorded in a variety of metals and alloys,[21, 42, 50] though in many instances the networks, unlike those of iron, are discontinuous, perhaps because of differences in lattice and impurity structures. Sub-boundaries may even be revealed in metals of the highest purity by the use of special etchants, but even so the few impurity atoms present are most likely to be associated with the dislocations and may initiate preferential etching attack.

The Gamma Boundaries

These boundaries have been observed previously[2, 3] after vacuum-etching, and a satisfactory theory has been put forward.[51]

The Nature of the Gamma-Ghost Boundaries

Although a satisfactory theory has been put forward[51] which will explain why vacuum-etching develops the γ boundaries as grooves, it cannot explain their detection by normal metallographic techniques. For the latter, some form of differential etching attack must occur, and the most likely cause for this is the segregation of an impurity at the γ boundaries during the austenitizing period. After the $\gamma \rightarrow \alpha$ transformation the impurities will be in unstable positions and tend to disperse; this dispersion will be prevented by rapid cooling, and the lines of concentration will be detected as γ-ghost boundaries.

There is insufficient evidence to identify with certainty the impurity or impurities responsible for showing up the γ-ghost boundaries. In view of the very low solubility of oxygen in γ-iron,[52] however, and the appearance of the microstructures, especially after electrolytic polishing, which tends to etch out oxide inclusions, it seems possible that oxygen may be the element concerned. On the other hand, there is evidence[41] to show that carbon will concentrate increasingly at the austenite grain boundaries with rising temperature and disperse with falling temperature.

The Structure of the Alpha-Boundaries

Evidence that the grain boundaries in etched low-carbon irons are raised above the matrix level has been obtained with the light microscope, using oblique illumination,[24] and by electron microscopy.[53] It has also been shown[25] that the α boundaries in a purified Cr ferrite appear as grooves which become ridges after the addition of 0·04% of carbon. Electron-diffraction patterns from raised boundaries in a low-carbon iron specimen quenched from 700° C indicated the presence of a structure identical with austenite containing 0·85–1·7% C.[40]

In the present investigation, grain-boundary ridges were observed in Armco iron specimens in the following conditions: (i) annealed, (ii) normalized, (iii) quenched and tempered, and (iv) equilibrium annealed (as in Section 9, Table II). Grain-boundary grooves resulted when Armco iron was (i) soaked for long

periods in air at 850° C, (ii) recrystallized in the α range (Section 10*a*, Table II), (iii) vacuum-etched in the γ range, and (iv) thoroughly decarburized (Section 8*b*, Table II).

In partially recrystallized specimens grooves were observed in the recrystallized areas (Fig. 8) and ridges elsewhere (Fig. 9).

In some conditions the purer N.P.L. and B.I.S.R.A. irons behaved differently from the Armco iron. Thus, although ridges were observed in annealed and normalized specimens, grooves resulted when these irons were quenched from the 950–700° C range. These results, quoted for all the irons, were obtained whether the specimens were examined as electropolished, or etched in nital, picral, or aqueous picric acid.

From the available evidence it seems likely that carbon at the grain boundaries is responsible for the ridging effect, and its removal from them by decarburization, internal oxidation, or recrystallization results in the appearance of grooves.

It was thought that specimens made from material treated to develop the grain-boundary-groove type of structure might provide some useful data on the problem of the discontinuous yield in iron. Such specimens were prepared from cold-worked and vacuum-recrystallized bars of Armco iron and tested in the Hounsfield Tensometer. For some as yet inexplicable reason tensile failure occurred by intergranular fracture at between 8 and 10 tons/in² with correspondingly lower yield stresses; material with the more normal grain-boundary structure fractured at about 20 tons/in².

CONCLUSIONS

The investigation described in the paper led to the following conclusions:

(1) Alpha-veining is a feature normally present in the structure of low-carbon irons, and the phenomena associated with it may be explained in terms of a sub-grain structure within the ferrite. The ease of observation depends on the presence and state of impurities within the metal, but their removal does not affect the underlying sub-structure. Carbon and nitrogen are the impurities most likely to concentrate at the sub-grain-boundary networks, so making them readily visible under the microscope. The sub-grains themselves are formed as a result of the plastic deformation consequent upon the $\gamma \rightarrow \alpha$ transformation.

(2) Only in the absence of sub-grains is α-veining completely eliminated in the sense that it cannot be detected, even by deep etching. Destruction of the sub-grains occurs when more perfect grains are formed by a method, such as recrystallization in the α-range, which does not involve the $\gamma \rightarrow \alpha$ transformation.

(3) The γ-ghost boundaries are observed when γ boundaries are outlined by the segregation of an impurity or impurities and when these are trapped *in situ* by sufficiently rapid cooling. On the evidence available it seems likely that carbon or oxygen is the element responsible.

(4) The appearance of ferrite grain boundaries as surface ridges in etched micro-sections of low-carbon irons indicates an appreciable concentration of impurity atoms along them. From the available evidence carbon appears to be responsible for this effect.

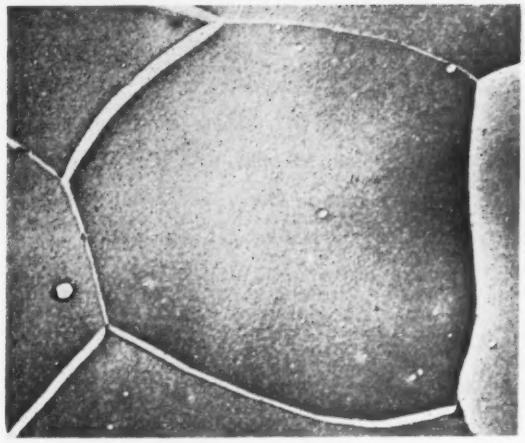


Fig. 9—Ridged α-grain boundaries in unrecrystallized area of Armco iron specimen described in Fig. 8. Formvar negative replica × 3800

(5) Much of the confusion in the literature has been caused by (*a*) failure to realize that α-veining is due to the existence of a sub-structure which becomes increasingly easy to detect as impurity elements concentrate along the sub-boundaries and, (*b*) similarity in appearance, though not in response to suitable heat-treatment, between α-veining and the structure of partially recrystallized ferrite.

Acknowledgments

The authors are grateful to their colleagues in the Department of Metallurgy for their interest and help in this work. One of them (P.S.) wishes to thank the Company of Cutlers in Hallamshire for the award of a Goodwin Fellowship during the tenure of which this study was made.

References

1. T. Andrews: *Proc. Roy. Soc.*, 1895, vol. 58, pp. 59–64.
2. H. S. Rawdon and T. Berglund: U.S. Bureau of Standards, 1928, Scientific Paper 571.
3. A. L. Tarr: *Metals and Alloys*, 1936, vol. 7, p. 130.
4. W. Rosenhain and J. C. W. Humfrey: *Proc. Roy. Soc.*, 1910, vol. 83, ser. A, pp. 200–209.
5. J. C. W. Humfrey: *Iron Steel Inst., Carnegie Scholarship Memoirs*, 1912, vol. 4, pp. 80–107.
6. J. H. Whiteley: *J. Iron Steel Inst.*, 1920, No. I, p. 377.
7. C. O. Bannister and W. D. Jones: *Ibid.*, 1931, No. I, pp. 395–409.
8. G. K. Burgess and J. J. Crowe: *Bulletin of the U.S. Bureau of Standards*, 1914, vol. 10, pp. 315–370.
9. F. Sauerwald, W. Schultze, and G. Jackwirth: *Zeitschrift für Anorganische Chemie*, 1924, vol. 40, pp. 384–390.
10. F. S. Tritton and D. Hanson: *J. Iron Steel Inst.*, 1924, No. II, pp. 90–121.
11. R. A. Hadfield: *Ibid.*, No. II, pp. 233–235.
12. F. S. Tritton: *Metallurgist*, 1927, vol. 3, pp. 88–90.
13. E. Ammermann and H. Kornfeld: *Stahl u. Eisen*, 1929, vol. 49, pp. 1192–1195.
14. *Metallurgist*, 1929, vol. 5, p. 147.
15. E. Ammermann and H. Kornfeld: *Arch. Eisenhüttenwesen*, 1933, vol. 7, pp. 307, 311.
16. H. O'Neill: *J. Iron Steel Inst.*, 1929, No. II, pp. 207–233.
17. L. Northcott: *Ibid.*, 1932, No. II, pp. 267–287.

18. H. HANEMANN *et al.*: *Arch. Eisenhüttenwesen*, 1933, vol. 6, pp. 567–570.
19. E. AMMERMANN and H. KORNFELD: *Ibid.*, 1933, vol. 7, pp. 567–570.
20. W. EILENDER and H. CORNELIUS: *Ibid.*, 1935, vol. 9, pp. 263–264.
21. L. NORTHCOTT: *J. Inst. Metals*, 1936, vol. 59, pp. 225–253.
22. L. NORTHCOTT: *Metallurgist*, 1936, vol. 10, pp. 165–167, 184–186.
23. N. P. GOSS: *Trans. Amer. Inst. Min. Met. Eng.*, 1941, vol. 145, pp. 272–280.
24. A. HULTGREN and B. HERRLANDER: *Ibid.*, 1947, vol. 172, pp. 493–509.
25. J. HOCHMANN: *Rev. Mét.*, 1951, No. 10, pp. 734–758.
26. P. JACQUET: *Sheet Metal Ind.*, 1949, vol. 26, pp. 577–584.
27. A. KROLL, jun.: *J. Iron Steel Inst.*, 1910, No. I, p. 320.
28. A. SAUVEUR and C. H. CHOU: *Trans. Amer. Inst. Min. Met. Eng.*, 1929, pp. 350–360.
29. D. MCLEAN: *J. Inst. Metals*, 1948, vol. 74, pp. 95–100.
30. J. E. BURKE and C. S. BARRETT: *Trans. Amer. Inst. Min. Met. Eng.*, 1948, vol. 175, pp. 106–117.
31. C. S. SMITH: *Ibid.*, pp. 15–51.
32. C. NUSBAUM and N. P. GOSS: *Trans. Amer. Soc. Metals*, 1935, vol. 23, pp. 621–632.
33. N. P. ALLEN *et al.*: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 108–120.
34. E. W. WILLIAMS and H. O'NEILL: *Ibid.*, 1954, vol. 177, pp. 224–228.
35. J. M. BURGERS: *Proceedings of the Royal Netherlands Academy of Sciences, Amsterdam*, 1939, vol. 42, pp. 301–308, 309–316.
36. W. SHOCKLEY and W. T. READ: *Phys. Rev.*, 1949, vol. 75, p. 692.
37. P. LACOMBE and L. BEAUJARD: "The Strength of Solids," pp. 91–94: 1948, London, The Physical Society.
38. A. H. SMITH and F. C. THOMPSON: *J. Iron Steel Inst.*, 1952, vol. 171, pp. 38–40.
39. E. S. DAVENPORT and E. C. BAIN: *Trans. Amer. Soc. Metals*, 1935, vol. 23, p. 1060.
40. J. W. MENTER *et al.*: *Proc. Phys. Soc.*, 1952, vol. 65, ser. B, pp. 305–306.
41. J. W. SPRETNAK and R. SPEISER: *Trans. Amer. Soc. Metals*, 1954, vol. 46, pp. 1089–1135.
42. P. BRIDGMAN: *Proceedings of the American Academy of Arts and Sciences*, 1924, vol. 60, p. 305.
43. C. S. SMITHELLS and H. S. ROOKSBY: *Nature*, 1927, vol. 120, pp. 226–227.
44. W. H. GEORGE: *Ibid.*, 1935, vol. 136, p. 392.
45. K. H. MOORE: *Phys. Rev.*, 1934, vol. 45, p. 296.
46. P. J. E. FORSYTH: *J. Inst. Metals*, 1951, vol. 80, pp. 181–186.
47. D. MCLEAN *et al.*: *Nature*, 1950, vol. 165, p. 70.
48. J. A. RAMSEY: *Ibid.*, 1950, vol. 166, pp. 867–868.
49. J. A. RAMSEY: *J. Inst. Metals*, 1951, vol. 80, pp. 167–171.
50. D. L. DELAZARO and W. ROSTOKER: *Acta Met.*, 1953, vol. 1, pp. 674–678.
51. R. SHUTTLEWORTH: *Metallurgia*, 1948, vol. 38, pp. 125–131.
52. J. A. KITCHENER *et al.*: *Acta Met.*, 1953, vol. 1, pp. 93–101.
53. J. TROTTER *et al.*: "Metallurgical Applications of the Electron Microscope," pp. 75–83: 1949, London, The Institute of Metals.

The Traffic of Iron and Steelworks

LOCOMOTIVE OPERATING

By M. D. J. Brisby, Ing. Dipl., A.M.I.Prod.E., Assoc.Inst.T., and J. H. Turnbull, B.Com., A.M.Inst.T.

Introduction

A STUDY of locomotive operating costs at different works shows that these range from 27*s.* to 36*s.* per locomotive working hour for steamers, and from 20*s.* to 23*s.* for diesels.[1] These figures, however, are based on total costs for the locomotive fleet over one year and do not give the real cost of an effective locomotive working hour.

Two factors affect the ' working hour ' cost: firstly, *utilization*, or the actual number of hours in the shift that a locomotive is usefully employed on traffic duties, and secondly, *availability*, or the actual number of hours in the shift or shifts in the year that it is available for work.

These two concepts, quite distinct in so far as they provide different measures of efficiency, are nevertheless intimately related. Essentially, utilization

SYNOPSIS

The paper examines the levels of locomotive utilization and availability obtained from studies of steam and diesel locomotives in various works. Methods of improving both utilization and availability are suggested. These cover the organizational aspect of locomotive working, which has its main effect on utilization, and the scheduling of repairs by preventive maintenance techniques, which has its main effect on availability. The effect of utilization and availability on costs is discussed, and the relationship between steam and diesel is examined in its financial aspects. 1193

Paper OR/4/55 of the Operational Research Section of the British Iron and Steel Research Association, received 22nd July, 1955.

Mr. Turnbull is with the Association's Operational Research Section, and Mr. Brisby, formerly with the Section, is now with the Iron and Steel Board.

depends on the day-to-day efficiency of the traffic department, the type of duties involved, the degree of planning, and the overall level of supervision, and availability depends on the amount of servicing, maintenance, and repair work undertaken and the speed with which this work is carried out. The level of locomotive utilization must, however, depend on the general standard of maintenance since, other things being equal, well-maintained locomotives will doubtless give better service.

This report examines the levels of locomotive utilization and availability in a number of works and suggests methods of raising their values by improving the organizational aspects of locomotive working and repair scheduling. Finally, the report shows the bearing which these improvements can have on locomotive costs.

LOCOMOTIVE UTILIZATION

Utilization is defined here as the percentage time the locomotive is working in the shift. The figure is obtained by deducting from the 8-h shift the time the locomotive is not working owing to servicing, meals, and delays. Utilization figures for both steam and diesel locomotives obtained at one works under identical conditions are given in Table I, with further examples in Appendix I. These studies are useful for drawing comparisons between individual locomotives employed on different jobs. They give an indication of local traffic working conditions and the level of ' busy-ness ' of the locomotive. If the studies are repeated from time to time they will provide a means of detecting any improvement or deterioration in locomotive operation.[2]

Statistics of the type kept by main-line railways, such as ' tons handled ' and ' ton-miles,' are of little value in gauging the effectiveness of locomotive services in a steelworks as the jobs which have to be done vary so widely. No fair comparison, for example, can be drawn between a locomotive handling slag ladles up a tip and a yard locomotive on shunting duties on the level.

It is obviously impossible to ensure full utilization, but there is scope for improvement in most works. Extensive time studies of locomotive duties have shown that the time spent on actual work for both steamers and diesels is only about 50% of shift time.

From Table I the following interesting points emerge:

(i) Servicing time during the shift is very much less for diesels (about 2%) than for steamers (about 20%)

(ii) The time spent standing for ' no work ' is much greater for diesels than for steamers. This is because the diesel does not fill in time with servicing

(iii) The ' no work ' times for locomotives on production jobs, whether steam or diesel, are higher than on general duties. This is because service is the prime consideration on production jobs, whilst it is utilization which counts most on general duties. This point will be discussed later.

The time spent servicing steam locomotives frequently amounts to about 20% of the shift time. This figure, which includes time for coaling, watering, fettling, and minor running adjustments, is unnecessarily high owing to ' early finish and late start ' extending these operations when they are planned to coincide with shift change-overs. Except for locomotives working on steep gradients and exceptionally heavy traffic, servicing time for a steamer in reasonably good condition should not amount to more than 10–12% of shift time.

Table I
LOCOMOTIVE OCCUPATION
Percentage Shift Time

		Steam		Diesel	
		Production	General Duties	Production	General Duties
SHIFT AVAILABILITY	Running: Loaded	7·3	13·5	26·7	27·7
	Running: Light	40·3	33·6	18·5	18·8
	Shunting	1·5	3·4	0·4	7·8
	Weighing				
		49·1	50·5	45·6	54·3
UTILIZATION	Delays	5·2	6·0	8·1	10·9
	Meals	6·2	6·3	5·6	6·2
	No work	23·8	12·0	38·1	26·5
		35·2	24·3	51·8	43·6
		84·3	74·8	97·4	97·9
	Servicing	15·7	25·2	2·6	2·1
		15·7	25·2	2·6	2·1
		100·0	100·0	100·0	100·0

Delays to locomotives are found to range from 5% to 10% of total shift time in a works with an efficiently organized traffic system. The greater delays for the diesel locomotive shown in Table I are due to the fact that these operate in the more congested areas of the works. In some works these delays may rise to 20–25% (*see* Appendix I). These delays are largely due to conflicting movements or line occupation and to accidental causes, such as derailments, mechanical faults, or lack of steam.

Delays due to conflicting movements usually come from having too many locomotives working too close to each other, and can sometimes be reduced by planning shunting operations to avoid local congestion. Line occupation delays may be due to volume of traffic, but more often they are due to someone leaving a wagon where it should not be. If there is real congestion, planning can often help by ensuring that auxiliary operations avoid peak-load periods.

The most frequent causes of additional delays are derailments due to poor conditions of track, particularly at points and crossings. Badly packed sleepers, poor drainage, and off-gauge track are current sources of trouble. Breakdowns are rare, particularly where works have a good maintenance scheme, but delays due to lack of steam are frequent where locomotives are not really up to the job, as is sometimes the case with slag-tip locomotives.

The main reason for low utilization is established custom and practice for stopping and starting times, linked with preparation times for steam locos, and carried forward into diesel practice.

The large amount of time spent standing because of ' no work ' may be due to the fact that there is genuinely no work for the locomotive to do at the time, but it may also be due to bad communications. The most practical solution here is to adopt very high frequency radio communication. At least two works are using radio on their locomotives with considerable

Table II
YEARLY LOCOMOTIVE AVAILABILITY

(*a*) Steamers

Av. Age and Size of Fleet	Works A*	Works B	Works C†	Works D	Averages for 4 Works
	25 years (20 locos)	32 years (10 locos)	14 years (47 locos)	29 years (21 locos)	
Shed maintenance	5·6	13·8	10·6	15·3	11·3
Shop maintenance	14·1	8·7	8·4	14·0	11·2
Spare	16·6	8·7	15·4	7·9	12·1
Working	63·7	68·8	65·6	63·8	65·4‡
Total	100	100	100	100	100

(*b*) Diesels

Average Age and Size of Fleet	Works B	Works D	Works E	Averages for 3 Works
	3 years (7 locos)	4 years (15 locos)	2 years (4 locos)	
Shed maintenance	2·4	8·9	10·3	7·2
Shop maintenance	7·2	6·8	8·3	7·4
Spare	...	0·5	3·8	1·4
Working	90·4	83·8	77·6	84·0‡
Total	100	100	100	100

* 2 locomotives on days only (working 44-h week—unrequired 124 h).
† 8 locomotives on days only (working 44-h week—unrequired 124 h).
‡ From Table I, steamers are occupied on average about 20% of shift time in servicing, and diesels for about 2%. This means that they are not available for this time. Therefore the working availability of steamers drops from 65·4% to about 52%, but for diesels from 84% only to about 82% on average.

advantage. With installation costs at less than 1% of the price of the locomotive, it is a worthwhile investment.

Planning Locomotive Services

To operate a fleet efficiently it is necessary to have an intimate knowledge of production requirements. With this knowledge locomotives should be allocated in such a way as to reduce idle time to a minimum and to ensure the optimum loading. If these two factors could be put into effect at the traffic manager's discretion, they would go far towards enabling him to work his fleet at the cheapest level.

Transport, however, is a *service*, and must therefore be ready to meet the requirements of the production departments. This inevitably means that priority for certain jobs will, at times, far outweigh all other considerations. For example, in one ironworks the hot-metal locomotive was found to spend a considerable time standing, as custom required its attendance when the blast-furnace was tapping.

It is in such cases that there is a degree of incompatibility between the call for high utilization and the request for immediate readiness. The traffic manager naturally wishes to utilize his locomotive to the fullest possible extent, whilst the production manager wants the locomotive to be ready to work at short notice at all times, a condition which can only be met if the locomotive is not fully occupied. It is more important, for example, to see that O.H. furnaces are not kept waiting for scrap than to insist on high utilization of steelplant locomotives.* When a high degree of readiness is wanted and the level of utilization is a secondary consideration, diesel locomotives have the advantage that they can be switched off.

Overall works planning of the traffic service is, of course, the responsibility of management, and economic considerations such as those just mentioned should not be neglected. When considering standards of service, it is the cost of having to put up with something short of ' the best ' which must be balanced against the cost of providing the additional service.

The best compromise between high utilization of a locomotive fleet and exacting production requirements can be found in skilful allocation of locomotives. These can be allocated to specific jobs, such as supplying materials to furnaces, or they can be detailed to operate in an area where they can be called upon to perform any duty within that area.[3] Neither system on its own is entirely satisfactory. It is preferable to operate the locomotive fleet by areas, but to put specific locomotives on to essential production jobs, such as the hot-metal and ingot traffic. This will enable the maximum utilization to be obtained from locomotives engaged on general duties while providing a high standard of readiness for locomotives on production jobs.

Local control within the overall plant should be left to the foreman on the site. He is in the best position to size up situations and decide the sequence in which jobs should be done.

LOCOMOTIVE AVAILABILITY

Availability is defined here as the percentage time the locomotive is in condition for work, measured over a period of one year. This figure is obtained by subtracting from the total period the time the locomotive is off duty for maintenance and fitting purposes and the time when it is held as spare. Availability figures for both steam and diesel locomotives are given in Table II. These are very useful in indicating to the works management the general level of efficiency of the locomotive fleet, but they can be misleading when used for drawing quantitative deductions between individual locomotives unless complete details are known of their condition and duties.

A comparison between Tables II*a* and *b* shows the following interesting points:

(i) Diesels work for a much greater proportion of the year than steamers (on average 84% for diesels and 65·4% for steamers). Despite the differences in maintenance and operating techniques there is remarkable

* A conservative estimate for the operating cost of a furnace is £15 per furnace hour; if it can be shown that furnace cycle times, on the average, are delayed for only 10 min as a result of lack of motive power, this alone would justify the cost of an additional locomotive on the supply services. In any 12-h period 7 furnaces will charge (in an 8-furnace shop): 10 min saved per furnace represents 1·17 h saved in the 12-h period, equivalent to £17 10*s*. To run an additional diesel locomotive for 12 h costs £15 (25*s*. per loco hour).

consistency in the working times for locomotives in the different works

(ii) Both shed and shop maintenance for diesels occupy much less time than for steamers (on average 7·3% for diesels and 11·3% for steam)

(iii) Spare time for steamers is increased because it is standard practice to hold one or more spare locomotives in readiness in case of breakdowns in the working fleet.

Measured over the year, availability is largely dependent upon the age of the locomotive fleet, the duties it has to perform, its state of repair, and the maintenance policy of the works.

Age of Fleet

It is not easy to find a true relationship between age and availability as reliable records of locomotive failures are not generally available. Locomotives which are showing signs of weakness are frequently kept in service until their next period of shed maintenance. Moreover, it is difficult at times to assess the age of a fleet. The dates of purchase of the locomotives do not always give a true picture, as some works strip their locomotives to the frame and virtually rebuild them. The best compromise for steamers is probably to take the age of the boiler. This difficulty does not yet arise with diesels as they are all fairly new in the industry.

Table III gives the availabilities over a period of one year of six steam locomotives of same make but different age.

The locomotives are from the same works and underwent similar general repairs.

Table III shows that as age increases

(i) Shed maintenance increases, as might be expected
(ii) Shop maintenance does not depend so much on the age of the locomotive as on the time elapsed since the last major overhaul
(iii) Spare time is increased: the older locomotives are given the lighter duties
(iv) Working time decreases.

Duties to be Performed

The duties a locomotive has to perform determine to a large extent the maintenance it will have to undergo, and consequently its level of availability. A locomotive working on a long haul up a steep gradient will have to be kept in better repair than one used for shunting in a yard.

State of Repair

There is considerable difference of opinion on what is considered to be a locomotive in ' fit state of repair,' depending on the standard of maintenance in the works. This standard in turn is largely dependent on the quality of service the production departments are prepared to accept and the money management are prepared to allocate to traffic.

Maintenance Policy

Policy has a most important bearing on availability: not only does it determine the level of efficiency of the fleet in service, but it also fixes the time locomotives spend in shed and in the fitting shop, the frequency of rebuilding, and the overall rate of replacement of the fleet.

Some works believe in spending the minimum time and money on maintenance, relying on spares when locomotives break down in service; others believe in keeping their locomotives in really good condition to make sure they do not fail. Again, some works believe in having a number of spare locomotives and carrying out repairs leisurely as and when required, whilst others rely on a minimum number of locomotives, first-class maintenance facilities, and very rapid repairs.

Many works today have a policy of planned maintenance.[4] This means that maintenance on locomotives is carried out according to a pre-arranged programme which sets out the type of repairs, when they are to be carried out, and how long they should take. Ideally, planned maintenance should be based on the day-to-day working requirements of the locomotives and their expected life, and the level of maintenance should be fixed accordingly. In practice, what usually happens is that works have a number of locomotives to service with limited shed and shop facilities. The nature and frequency of the repairs are worked out on a compromise between the requirements of the locomotives and the capacity of the repair shops.

Tables IV*a* and *b* show the maintenance policies adopted at different works for steam and diesel locomotives; details of the work carried out on the locomotives are given in Appendix II.

Table IV*a* shows that there is no short cut to good maintenance for steam locomotives. Works *A*, *B*, and *C* all believe in thoroughly good maintenance and, despite their different approach, plan to devote 8–10 weeks per year to shop and shed maintenance. Planned maintenance for diesels (Table IV*b*) also shows that, despite different approaches, maintenance requirements are of comparable duration at three works when considered on a yearly basis. Comparing Tables IV*a* and *b*, it is obvious that the time spent on maintenance for steamers is 2–3 times greater than that for diesels.

Objection is sometimes raised to the effect that planned maintenance " is all right in theory but won't work in practice." This argument is refuted by experience. At one works a comparison made between planned and actual maintenance times gave the results shown in Table V.

The good measure of agreement between the planned programme and the actual times taken to carry out the maintenance shows that it *is* possible to carry out maintenance in accordance with predetermined plans. However, to keep slavishly and uncritically to a planned maintenance scheme, once

Table III

YEARLY AVAILABILITIES OF STEAM LOCOMOTIVES OF DIFFERENT AGE

	Locos 1 and 2: 5 yr. old	Locos 3 and 4: 38 yr. old	Locos 5 and 6: 42 yr. old
Shed maintenance	12	13	16
Shop maintenance	10	17	10
Spare	4	7	12
Working	74	63	62
	100	100	100

it has been established, means that one of the greatest advantages of having such a scheme is lost, namely, the ability to adjust, in the light of experience, so that the minimum amount of maintenance is carried out consistent with adequate operational efficiency.

A further advantage of planned maintenance is that with a knowledge of the work to be done at predetermined times, it is possible to bring past experience to bear and so set standard times for the various jobs. From these standard times it is an easy step to establish standard costs.[1]

EFFECT OF UTILIZATION AND AVAILABILITY ON COSTS

By increasing the utilization of locomotives the cost per hour of effective work can be reduced considerably. If one takes steamer costs at 30*s.* per hour and diesel costs at 22*s.* 6*d.*, then for a steamer spending 50% of shift time on productive work and for a diesel at 60%, the *cost per hour of effective work* would be 60*s.* and 37*s.* 6*d.*, respectively; Fig. 1 illustrates this.

Diesels do not show greater shift utilization than steamers on the figures presented in this paper. This, however, is because most traffic departments tend to use diesels at the same 'pressure' as steamers, as evidenced by the figures for 'no work' given in Table I. With servicing times of 2% of shift time for diesels compared with 20% for steamers it should be possible to achieve 70% utilization for diesels. This means that fewer diesels than steamers are needed to do any given amount of work.

If one considers the shift utilization possible with a diesel compared with a steamer, even assuming 60% for steam and 70% for diesel (a comparison very favourable to steam), six diesels can do the work of seven steamers. But the diesels are available for a greater proportion of the year than steamers. The diesel can work for 48 weeks in the year, the steamer

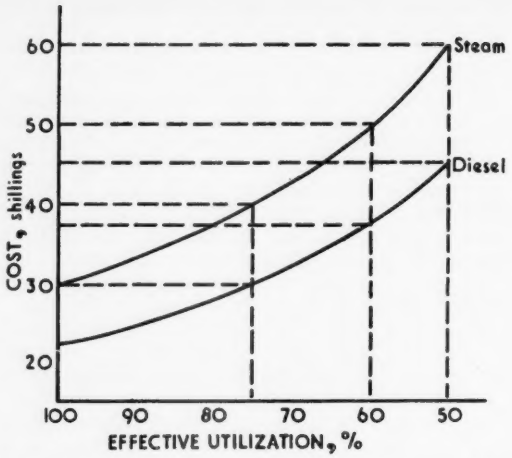


Fig. 1—Relative costs per hour of effective work for steam and diesel locomotives

for 42 (Tables IV*a* and *b*). Thus, eight steam locomotives can be replaced by seven diesels and still provide the same level of availability.

Combining these two advantages produces the conclusion that only three diesels are needed to replace four steamers, which can be summarized in tabular form:

	Steam	Diesel	Comparison
(i) Utilization	60% of shift	70% of shift	6 diesels = 7 steamers
(ii) Availability	42 weeks per yr.	48 weeks per yr.	7 ,, = 8 ,,
(iii) Combined (i) and (ii)	60% for 42 weeks per yr.	70% for 48 weeks per yr.	3 ,, = 4 ,,

So far as capital charges are concerned, even on a

Table IV

PLANNED MAINTENANCE: STEAMERS AND DIESELS

Type of Maintenance	Works A		Works B		Works C		Works D	
	Frequency	Time Taken	Frequency	Time Taken	Frequency	Time Taken	Frequency	Time Taken
(*a*) Steamers								
Lubrication	Daily	...			Daily	...		
Cleaning	3 days	...	Daily	(in traffic) 1½ h	Daily	...		
Washouts	10–12 days	2 shifts	10–12 days	2 shifts	11 days	3 shifts		
Periodic repairs	4–6 weeks	2½–3 shifts	...	...	2½ yr.	2 weeks		
Rebuilds (major)	2½–3 yr.	3–4 months	2½–3 yr.	3 mths.	5 yr.	3 months		
,, (partial)					5 yr.	4 weeks		
Planned maintenance (shop and shed) per loco	10 weeks per yr. (approx.)		8 weeks per yr. (approx.)		9 weeks per yr. (approx.)			
(*b*) Diesels								
Lubrication	Weekly	2½ h	Weekly	½ h			Fortnightly —300 h	1 shift
Cleaning	Daily	...	Daily	1½ h				
Minor repairs	Monthly (500–600 h)	3 shifts	Monthly	1–2 shifts			Monthly—600 h	2 shifts
Partial repairs	2500 h	1 week	(2000 h for large locos only)	5–6 weeks			6-monthly	4 shifts
Major repairs	20,000 h	9 weeks	2–2½ yr.	5–6 weeks			Yearly	2–2½ weeks
Planned maintenance per loco	6 weeks per yr. (approx.)		3½ weeks per yr. (approx.)				3½ weeks per yr. (approx.)	

'three for four' basis, there could still well be an appreciably greater capital involved with a diesel fleet than with steam locomotives. The present cost of a 400-h.p. diesel locomotive is £22,000 or more, whilst for a steamer of comparable power (i.e. one with 17-in. cylinders) the cost is about £12,500. It is interesting that in the lower power ranges the purchase price of a diesel is nearly comparable with that of a steamer. As power increases the diesel becomes relatively much more expensive. This price differential may well narrow as more experience is gained in the manufacture of large diesel locomotives, as these are all of comparatively recent introduction. An indication of present-day price ranges is given in Appendix III.

Although the capital expenditure on diesels is greater than for steamers, the greater availability of the diesel means that, so far as depreciation charges are concerned, much of the difference disappears when depreciation is expressed in terms of working weeks for the fleet. Taking the above figures as an example and using the 'three for four' basis, the capital expenditure for three diesels would be £66,000 and for four steamers £50,000. With 12% for depreciation and interest on capital, the cost of depreciation and interest on capital would be £165 per working week for three diesels and £143 per working week for four steamers. The annual figures are £7920 and £6000, respectively.

However, with running costs, the diesels show up to great advantage. The hourly running cost for a steamer is about 30*s*., whilst for a diesel 22*s*. 6*d*. is an average figure. Thus on the 'three for four' basis, the steamers would be about 60% more expensive than diesels on an hourly running-cost basis.

In terms of money, three diesels would cost £27,216 for 48 weeks of 168 h plus £7920 for depreciation and interest at 12%. For steamers the figures are £42,336 for 42 weeks of 168 h plus £6000 for depreciation. This shows an annual saving of £13,200 for an extra £16,000 of initial outlay in the example used in this paper.

If maintenance services are assumed to cost about 7*s*. 6*d*. per hour for steam and 5*s*. per hour for diesel, the annual maintenance cost, on the basis of availability, works out at approximately £2100 for a steam locomotive and approximately £1800 for a diesel. This ratio has been found in practice in a works with a mixed fleet, having some post-war steam locomotives and also some diesels which have been in service long enough to have reached the stage of requiring engine and gearbox replacements. Thus it is considered that this comparison is realistic and fairly represents the difference between steam and diesel maintenance costs.

CONCLUSIONS

(1) Planning locomotive services must result in a compromise between the traffic manager's desire to have his locomotives usefully occupied for as long as possible and the production department's desire to have a locomotive immediately ready to work when wanted. In practice, the best solution is to allocate a portion of the fleet to areas in the works where they are free to carry out a variety of jobs within the area, but to reserve a number of locomotives for essential production jobs, like the hot-metal and ingot traffic. This enables the maximum utilization to be obtained from locomotives engaged on general duties while ensuring a high standard of readiness for the locomotives on production jobs.

When considering standards of service, it is the cost of having to put up with something short of 'the best' which must be balanced against the cost of providing the additional service.

(2) Utilization figures are useful for drawing comparisons between individual locomotives. They give an indication of local traffic conditions, and provide a standard against which to measure any improvement or deterioration in operating efficiency.

Time studies show that the time spent on actual work for both steamers and diesels is only about 50% of shift time. The potential for diesels, however, is much higher. Servicing time for steamers, which includes time for coaling, watering, fettling, and minor running adjustments, is unnecessarily high owing to 'early finish and late start' extending these operations when they are planned to coincide with shift changeover.

Standing time waiting for work, which can range from 12% to 38% of shift time, is indicative of power not fully utilized. Radio communication can do much to reduce idle time by giving the drivers advance notice of work to be done.

Delays can amount to 20% of shift time and may be due to conflicting movements, line occupation, or accidental causes such as derailments, mechanical faults, or lack of steam. A knowledge of the causes of delay usually suggests the cure.

Table V

MAINTENANCE TIMES—PLANNED AND ACTUAL

Type of Maintenance	Planned Programme, weeks per loco year	Actual Programme, weeks per loco year					
		1950	1951	1952	1953	1954	Average 1950–54
Major rebuilds	2·1	1·3	...	1·4	3·0	2·8	1·7
Partial ,,	0·8	0·7	2·0	1·2	...	0·4	0·9
Periodic ,,	0·8	1·1	1·0	0·5	0·6	0·5	0·7
Total time on shop maintenance (per loco year)	3·7	3·1	3·0	3·1	3·6	3·7	3·3

(3) Availability figures give a useful indication of the general level of efficiency of a locomotive fleet. Measured over the year, availability is largely dependent upon the age of the fleet, the duties it has to perform, its state of repair, and the maintenance policy of the works.

It has been found that diesels work for a much greater proportion of the year than steamers (84% as against 65·4%). Also shop and shed maintenance for diesels occupies less time than for steamers (7·3% against 11·3%).

(4) There is no short cut to good maintenance. Despite the different approaches to this problem, the works investigated all devote 8–10 weeks per year to maintaining a steamer, and 3½–6 weeks to maintaining a diesel. The shed and shop times for steamers are thus 2–3 times greater than for diesels. Planned maintenance schemes in which carefully laid-out repair schedules and standard times are fixed are found to be a thoroughly practical proposition.

Maintenance costs for steamers and diesels are comparable and work out at approximately £2100 per year for a steamer and £1800 for a diesel.

(5) Combining the advantages of greater utilization and availability, one reaches the conclusion that three diesels can replace four steamers. Even on this basis the capital outlay involved with a fleet of diesels is appreciably higher than for a fleet of steamers, but diesels are considerably cheaper to run, the hourly costs being of the order of 22*s*. 6*d*. for diesel against 30*s*. for steamers, thus more than offsetting the slightly higher depreciation charges. On the ' three for four ' basis this means that operating costs for a fleet of diesels would be about 60% cheaper than for a fleet of steamers.

References

1. J. H. TURNBULL: *Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, pp. 17–21.
2. H. H. MARDON and M. D. J. BRISBY: *J. Iron Steel Inst.*, 1949, vol. 163, pp. 433–448.
3. E. R. S. WATKIN: *Brit. Iron Steel Res. Assoc.*, Conference on Works Transport, 1954, pp. 22–24.
4. C. E. ROEBUCK: *Ibid.*, pp. 25–28.

APPENDIX I

Locomotive Occupation (Percentage Shift Time)

TYPICAL EXAMPLES FOR STEAMERS

Production Departments

Shift Duty: 8 h		Blast-Furnace Hot Metal		Blast-Furnace Slag		Steelplant		Rolling Mills	
AVAILABILITY / UTILIZATION	Running:								
	Loaded	11·0		31·8		14·5		19·4	
	Light	8·5		5·4		13·5		10·4	
	Shunting	35·8		17·4		21·0		34·2	
	Weighing	...		...		2·5		2·2	
			55·3		54·6		51·5		66·2
	Delays	20·6		26·3		22·5		16·8	
	Meals	7·0		6·2		7·0		6·4	
	No Work	...		...		...		...	
			27·6		32·5		29·5		23·2
			82·9		87·1		81·0		89·4
	Servicing	17·1		12·9		19·0		10·6	
			17·1		12·9		19·0		10·6
			100·0		100·0		100·0		100·0

General Services

Shift Duty: 8 h		Gen. Duty		Gen. Duty		Stockyard		Yard Loco	
AVAILABILITY / UTILIZATION	Running:								
	Loaded	15·0		16·8		13·0		16·5	
	Light	5·0		12·9		8·2		8·8	
	Shunting	38·0		26·8		30·3		32·8	
	Weighing	...		...		1·9		2·6	
			58·0		56·5		53·4		60·7
	Delays	19·0		18·3		26·0		19·8	
	Meals	...*		5·6		6·6		6·2	
	No Work	...		...		...		...	
			19·0		23·9		32·6		26·0
			77·0		80·4		86·0		86·7
	Servicing	23·0		19·6		14·0		13·3	
			23·0		19·6		14·0		13·3
			100·0		100·0		100·0		100·0

* Relief Driver

Supply Lines

Shift Duty: 8 h		Reception Sidings to Works		Mines to Works		Wharf to Works	
AVAILABILITY / UTILIZATION	Running:						
	Loaded	26·9		21·0		19·0	
	Light	3·5		11·7		2·5	
	Shunting	25·0		8·7		31·3	
	Weighing	15·0		5·6		2·5	
			70·4		47·0		55·3
	Delays	5·3		3·7		8·3	
	Meals	5·3		7·3		9·4	
	No Work	...		...		...	
			10·6		11·0		17·7
			81·0		58·0		73·0
	Servicing	19·0		42·0		27·0	
			19·0		42·0		27·0
			100·0		100·0		100·0

TYPICAL EXAMPLES FOR DIESELS

Production Departments

Shift Duty: 8 h		Ingots		Scrap Shed		Casting Bay		Blast-Furnace	
AVAILABILITY / UTILIZATION	Running:								
	Loaded / Light	22·3		17·2		40·0		27·1	
	Shunting	5·5		33·6		18·8		16·1	
	Weighing	...		...		...		1·4	
			27·8		50·8		58·8		44·6
	Delays	9·7		11·6		3·9		7·2	
	Meals	2·1		5·8		7·3		7·2	
	No Work	59·0		27·0		27·9		38·7	
			70·8		44·4		39·1		53·1
			98·6		95·2		97·9		97·7
	Servicing	1·4		4·8		2·1		2·3	
			1·4		4·8		2·1		2·3
			100·0		100·0		100·0		100·0

General Services

Shift Duty: 8 h		General Duty		Slack		Ore Handling	
AVAILABILITY / UTILIZATION	Running:						
	Loaded / Light	24·0		30·2		28·8	
	Shunting	18·0		26·6		11·7	
	Weighing	3·3		8·6		11·5	
			45·3		65·4		52·0
	Delays	7·5		8·5		16·7	
	Meals	6·1		6·2		6·2	
	No Work	41·1		18·5		20·0	
			54·7		33·2		42·9
			100·0		98·6		94·9
	Servicing	...		1·4		5·1	
			...		1·4		5·1
			100·0		100·0		100·0

APPENDIX II

Maintenance Schedules

Diesel Locomotives

	Frequency	Maintenance Work
Works A	Daily	(By driver) Look over loco, check oil and water levels, lubrication
	Weekly	(By fitter and driver) Same as daily, plus check battery and generator; clean filters; check shaft cover and connecting rod bolts; inspect fuel injection nozzles; blow-out motors and grease bearings
	Monthly (500–600 h)	(By engineers in loco repair shop) Loco blown out with dry air, positioned over pit, covers off traction motors, brush gear checked, oil changed, cylinder-head gaskets checked.
	2500 h	(By engineers in repair shop) Includes monthly inspection. Testing air brakes, removal of cylinder heads, thorough cleaning, checking valves and seats and grinding in, draw pistons and clean, liners inspected for wear, check camshaft drive, governor, and fuel pump. Hot spot plugs examined and changed if necessary. Fuel and lubrication oil circuits checked by hand pump. Examine and overhaul traction motors.
Works B	Daily	Lubrication and superficial cleaning. Minor adjustments carried out in running shed if necessary.
	Weekly	Air filter changes. Minor adjustments carried out in running shed if necessary.
	Monthly	Oil changed, general inspection, brake blocks, adjustments to fuel sprays and minor repairs. Engine thoroughly cleaned.
	2–2½ yr. or 2000 h (depending on type of loco)	This includes monthly inspection, wheel turning and a complete engine and transmission overhaul.
Works D	Fortnightly–300 h	Clean engine filters, etc., lubricate all parts. Check all oil levels, belts, etc., check and adjust brakes, sanding; check transmission, gear box, etc.; check frame, side rod bushes, draw bar, buffers, etc. Check contactors, generators, traction motors, compressors, batteries, etc.
	Monthly–600 h	Check all lubrication points; clean or renew filters and lubricate as necessary; remove and clean injectors, valves, etc., tappet clearances. Remove crank-case covers, thorough internal inspection, camshaft, etc. Check and adjust all brake gear, sanding gear, axle boxes, bogies, wheels, springs, bearings, etc. Thorough check of all gearbox and transmission and all lubricants and lubrication systems.
		Insulation tests; check generators, traction motors, compressors, batteries, lights, ancillary equipment, etc.
	6-monthly	Repeat work done under 'monthly.' Clean air compressor, air filters, oil strainers, drain and flush cooling system; remove cylinder head, decarbonize, grind in valves, grind and check air start valves. Check all brake equipment, remove and inspect air compressor valves, check crankshaft alignment.
		Remove cylinder head and carry out whatever work is necessary.

Steam Locomotives

	Frequency	Maintenance Work
Works A	Daily–3days	Lubrication and cleaning by driver. Thorough cleaning by special squad.
	10–12 days	Cleaning, washing out, tube sweeping, and adjustments.
	4–6 weeks	Locomotive withdrawn from service for minor adjustments and repairs, reconditioning of connecting-rod brasses, slippers, cams, clacks, injector valves, and adjustment and fitting of brake blocks.
	2½–3 yr. (2–2½ yr. for light locos)	Locomotive thoroughly examined and parts requiring replacement or repair passed to engineers who plan rebuilds. Costs readily obtained by reference to works order.
Works B	Daily	Lubrication, superficial cleaning, minor repairs, brake adjustments, new gauge glasses, etc.
	10–12 days	All minor repairs and locomotive thoroughly cleaned, washing out.
	2½–3 yr.	Almost always includes a boiler patch, major work on wheels, boxes, etc. Locomotive repainted.
Works C	Daily	Lubrication by driver in traffic.
	11 days	Washout, tube sweeping, general cleaning and mechanical adjustments.
	3 yr.*	General mechanical overhaul.
	6 yr.*	Full mechanical overhaul including tyre turning and lesser boiler repairs.
	6 yr.*	Full mechanical overhaul including tyre turning and lifting boilers out.

* Periodic repairs are carried out on the following schedule:

Minor overhaul	2 weeks	
Working		80 weeks
Major/minor overhaul	5 weeks	
Working		50 weeks
Minor overhaul	3 weeks	
Working		111 weeks
Major overhaul	11 weeks	
Working		50 weeks
	21 +	291

= 6 years

Appendix III

Indication of Price Levels of Locomotives

Steam		Diesel	
15-in. cylinder	£8000	200 h.p.	£12,000
16-in. ,,	£10,000	300 ,,	£18,000
17-in. ,,	£12,500	400 ,,	£22,000
18-in. ,,	£15,000	500 ,,	£26,000

These figures are only intended to give an indication and are based on a 'basic model.' The addition of refinements such as roller-bearings, manganese liners on horn cheeks, copper fireboxes, etc. will raise the price of steamers considerably, whilst a 500–550-h.p. Bo–Bo diesel-electric locomotive for steelworks duty has been quoted at prices from £34,000 to £49,000.

ANDREW CARNEGIE RESEARCH REPORT

By W. S. Owen, M.Eng., Ph.D.
and J. Wilcock, B.Eng.

Reactions Involved in the First-Stage Graphitization of Iron–Carbon–Silicon Alloys

SYNOPSIS

The component reactions involved in the isothermal graphitization of a white iron–carbon–silicon alloy have been examined. The rate of growth of the graphite and of solution of cementite, the graphite nucleation frequency per unit volume and per unit austenite/cementite interfacial area, and the rate of decrease of this area have been measured. The interplay of these effects during the graphitization process is discussed and a growth model is proposed with a diffusion distance which increases as the reaction proceeds. 1078

BURKE AND OWEN[1] have discussed the general kinetic features of the isothermal solid-state graphitization reaction in terms of an empirical model. The overall reaction rate in high-purity iron–carbon–silicon alloys was measured dilatometrically; the model (*see* Burke and Owen,[1] Fig. 7) requires the following assumptions:

(i) The frequency of nucleation and the rate of growth of the graphite nodules determine the overall reaction rate. (It is implied that the rates of solution of cementite and of diffusion of carbon atoms away from the austenite/cementite interfaces are sufficient to maintain the general carbon level in the austenite at its initial value)
(ii) A constant carbon diffusion distance is maintained
(iii) The graphite grows as a perfect sphere
(iv) The nucleation frequency per unit volume is constant with time
(v) The growth rate of graphite is constant with time.

The validity of these assumptions was tested experimentally where possible. Microscopic examination of the alloys showed that assumption (iii) was only approximately correct, since most of the graphite particles were of the aggregate nodule variety. Measurements of nucleation frequency per unit volume and the rate of growth have shown that between about 5% and at least 70% of completion of the reaction, assumptions (iv) and (v) were reasonable. Rate equations for the overall reaction derived from the model gave remarkably good agreement with the dilatometric data; thus, it seems that the model provides an acceptable generalized view of the kinetics of the overall reaction.

However, it is clear that this empirical treatment of the problem can provide only an approximate description of the gross effect. At all temperatures in the austenite range assumption (i) is probably true for almost all reaction times, but it is doubtful if the other assumptions are even approximately correct over more than about three-quarters of the reaction time range. Thus, it seems that the close agreement between the experimental overall reaction rate and that predicted by the model must in part be accounted for by the existence of compensating errors. If a more precise description of the graphitization reaction is required, it is necessary to examine the component reactions in detail. Some studies with this objective are reported in this paper.

EXPERIMENTAL METHOD

The alloy used was made from high-purity materials by the method described in the earlier paper.[1] It contained 3·38% of carbon and 1·13% of silicon and was originally designated 35/3.[1]

Small microspecimens were annealed for times between zero and 100% reaction; similar series of experiments were performed at 892°, 946°, 972°, and 1001° C. The annealing was carried out in the vacuum chamber of the dilatometer so that there is a direct correspondence between the dilatometric and microscopic results.

The variations with time of the following quantities were measured:

(i) Graphite nucleation frequency per unit volume of specimen (I_v)
(ii) Rate of radial growth of graphite nodules (G)
(iii) Austenite/cementite interfacial area per unit volume of specimen (S_v)
(iv) Volume percentage of graphite
(v) Volume percentage of cementite.

The nucleation frequency per unit volume and the rate of growth of graphite were measured by the methods described in the earlier paper.[1]

Smith and Guttman[2] have shown that the area S of a three-dimensional array of surfaces (in this case the austenite/cementite interface) in a volume V can be measured by a simple method which involves counting the number of intercepts N which the surfaces make with random lines (length L) drawn in random planes (the planes of polish) through the volume. They deduce the relation

$$S_v = \frac{S}{V} = \frac{2\overline{N}}{\overline{L}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Manuscript received 18th November, 1954.
Dr. Owen is with the Department of Metallurgy, Massachusetts Institute of Technology, and Mr. Wilcock with the Department of Metallurgy, University of Liverpool.

A large number of readings of N and L were averaged (denoted by a bar in equation (1)), in which case the formula is independent of the shape of the cementite particles.

The nucleation frequency per unit interfacial area was obtained by combining measurements (i) and (iii). If N_v is the number of graphite nodules per unit volume and N_s the number per unit interfacial area at time t ($N_v = N_s = 0$ when $t = 0$), then the nucleation frequency in terms of interfacial area at time t is given by:

$$I_s = \frac{dN_s}{dt} = \frac{d}{dt}\left(\frac{N_v}{S_v}\right)$$
$$= \frac{1}{S_v^2}\left(S_v\frac{dN_v}{dt} - N_v\frac{dS_v}{dt}\right) \ldots\ldots(2)$$

All the terms on the right-hand side of equation (2) are readily evaluated from the experimental curves N_v/t and S/t. The results have been plotted as I_s/t curves in Fig. 1.

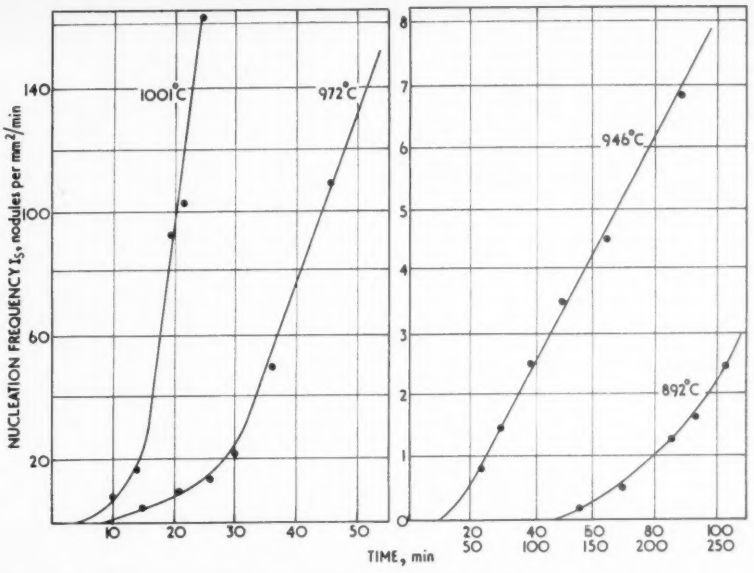


Fig. 1—Interfacial nucleation frequencies (the longer times on the abscissa refer only to the specimen graphitized at 892° C)

The volume percentages of graphite and cementite were measured by a microscopic method which has been fully discussed by Howard and Cohen.[3] The essential measurement is the total length of the intercept made by the area of the microconstituent in a random plane of polish with random lines of known length. This operation was carried out using an integrating micrometer of a design developed by A.T.J. Dollar. The accuracy of results was estimated by a statistical method, and sufficient readings were taken to obtain for the cementite measurements a 95% probability of an error less than $\pm 1\%$. In general, the graphite measurements are of the same order of accuracy. The difference in accuracy is greatest in specimens which have been reacted for short times so that the number of graphite nodules is small and the volume of cementite large.

REDISTRIBUTION OF GRAPHITE NODULE SIZE

In 1942, McMillan reported the surprising observation that on heating commercial white irons isothermally, at suitable temperatures, for longer times than required to remove all carbides, the number of graphite nodules per unit volume progressively decreases with time. This was confirmed by Brown and Hawkes,[4] who reported a maximum in certain nucleation frequency *v.* time curves. They have since described the process as one of ' coalescence ' of the nodules.[5] The term is misleading since it suggests mass movement of nodules through the matrix. Burke and Owen[1] are in agreement with the original suggestion of Brown and Hawkes[4] that the phenomenon is a " consequence of the dependence of solution potential on the radius of the graphite spheres," implying that the nodules with a radius less than some critical value redissolve, and carbon diffuses through the austenite and deposits upon larger growing nodules. In the present work, this mechanism was assumed to be operative. Since a redistribution of nodule size has a profound effect on the growth rate and the nucleation frequency of the graphite, it is necessary to consider the mechanism in greater detail.

The ideal equilibrium diagram does not take into account any surface-energy terms. It records the saturation concentration of solute with respect to a crystal of infinite size. In the practical case, the saturation concentration of carbon in austenite with respect to graphite is a function of the radius of the graphite nodule. This relationship is expressed by the Thomson–Freundlich formula:

$$\ln\frac{\gamma_1}{\gamma_2} = \frac{2\sigma}{\phi RT}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \ldots\ldots(3)$$

where γ_1 and γ_2 are saturation concentrations of carbon in austenite corresponding to graphite nodule radii r_1 and r_2, respectively; σ is the interfacial energy per unit area, and ϕ is the density of graphite.

In the present case, the term $2\sigma/\phi RT$ can be considered constant at constant temperature. It is clear that the solution potential of a graphite nodule is dependent not only upon the concentration of the austenite in contact with it, but also on the size of the nodule. Considering two neighbouring nodules, if r_2 is greater than r_1, then γ_1 must be greater than γ_2. If the concentration of carbon in the austenite γ in the vicinity of these nodules is greater than both γ_1 and γ_2, the austenite will be supersaturated with respect to both nodules and both will grow. If γ lies between γ_1 and γ_2 the austenite will be undersaturated with respect to the smaller nodule but supersaturated with respect to the larger; consequently, the smaller nodule will dissolve and the larger one will continue to grow. It is evident that no growth will take place

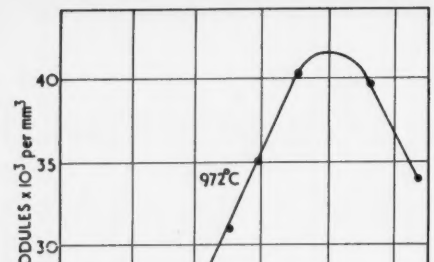


Fig. 2—Nodular count

unless γ is greater than $\gamma_{max.}$ where $r_{max.}$ is the radius of the largest nodule present in the specimen. If γ is considered to be a fixed composition, then the larger a nodule grows, the more supersaturated with respect to this nodule the austenite becomes. Thus, all nuclei which appear and grow at the start of the reaction must be greater than a critical size. Should the value of γ decrease, re-solution of some of the nodules can be expected, the first to dissolve being the smallest. There are two possible cases to consider. The carbon level in the austenite may start to fall as soon as graphitization starts, in which case re-solution of the smallest nodules takes place continuously throughout the reaction and simultaneously with the growth of the larger nodules. Alternatively, the rates of solution of cementite and diffusion of carbon atoms into the austenite may be sufficient to maintain a constant carbon level for an appreciable time. Then, no re-solution will occur until a time is reached when the carbon replenishment from the cementite fails to keep pace with the depletion resulting from the graphite growth. That is, re-solution will occur after a definite time interval. The former case, which assumes that the supply of carbon atoms from the cementite is restricted from the onset of the reaction, requires the growth of new nodules to be confined to volumes of austenite remote from existing growing nodules, since nuclei occurring in depleted austenite volumes would immediately redissolve. This prediction is not substantiated by microscopic observation of the distribution of the nodules. On the other hand, a sharp decrease in the number of microscopically visible graphite nodules after the reaction has progressed for a definite time (usually corresponding to between 70% and 100% transformation) has been observed by several investigators.[1, 4] Thus the second suggestion appears to be the more probable.

When all the cementite has disappeared (a time usually referred to as the end of the reaction) the austenite will be just saturated in the vicinity of the smallest existing nodules. Subsequently γ remains approximately constant. However, the interfacial energy per unit volume of graphite is greater for small nodules than for large, so that the energy of the system as a whole can be reduced by the growth of the large nodules at the expense of the small. Consequently, solution of small nodules will continue, supplying carbon atoms for the growth of larger nodules. Experimental observation of this phenomenon was first reported by McMillan.[6] The driving force for this reaction between a pair of nodules is a function of the difference in their radii. A minimum difference, the magnitude of which is a reciprocal function of temperature, is necessary for the reaction to proceed. It is clear that as the total number of nodules decreases the diffusion distances necessary for continuation of the reaction increase, so that, for this reason also, the reaction rate will decrease with time. One of the replots of McMillan's data reported by Brown[5] suggests that this is the case, but the remainder of the data are inadequate to decide the point.

NUCLEATION FREQUENCY

For alloy 35/3 the measured nucleation frequency per unit volume was plotted as a function of reaction time (Fig. 2). Since the method depends upon the microscopic observation of graphite nodules, the results refer to the number of nuclei which have grown to a size that can be detected by the optical microscopic technique used. Provided that no re-solution of sub-microscopic nodules occurs, a figure which is closely related to the true nucleation frequency is obtained from the calculation. As an example, the plot of the number of nodules per cubic millimetre against time at 972° C will be considered. Up to about 70% reaction, the number of nodules increases in a linear manner. This suggests that, in fact, any re-solution that occurs is of negligible consequence. The slope of the line, which is positive, may be regarded as the observed constant nucleation frequency (proportional to the true nucleation frequency) operative over this part of the reaction. At later times, the slope is negative, indicating that re-solution of both sub-microscopic and some microscopic graphite nodules is occurring. The maximum in the curve is well defined.

Earlier microscopic work has demonstrated that invariably the nuclei appear at the cementite/austenite interface. Since it is improbable that the surface area is appreciably altered by the relatively small carbon concentration changes in the austenite which occur during graphitization, it seems reasonable to assume that the effect on the true nucleation frequency is small. However, any nuclei that appear after re-solution of sub-microscopic nodules has set in cannot grow into the austenite since they are less than the critical size. Consequently, they will not be recorded in the microscopic nodule count. Obviously, meaningful nucleation frequency measurements can only be obtained up to the reaction time corresponding to the maximum in the N_v/t curves. The following discussion is confined to this range.

The observed constancy of nucleation frequency per unit volume with time is important since it justifies assumption (iv) which was made in earlier empirical studies of overall reaction rates. However, this value is the product of two variables: the nuclea-

tion frequency per unit interfacial area and the change of this area with time. The fact that, to a reasonable degree of accuracy, the product is a constant is in one sense fortuitous.

Since the appearance of nuclei is confined to the interfacial area, it is of interest to enquire whether or not preferred nucleation sites are located in this interface: i.e. whether nucleation requires the presence of a limited number of sub-microscopic foreign particles in the interface, or is a spontaneous reaction which can occur at any point in the interface (this type of nucleation can be referred to as interfacial ' homogeneous ' nucleation). The plots of nucleation frequency per unit area of interface against time for four different temperatures are shown in Fig. 1. These demonstrate that the nucleation is transient, the frequency progressively increasing with time. Avrami's theory[7] predicts that when the number of nucleation sites is limited there is a falling-off in nucleation frequency as the reaction time increases. There is no indication in any of the curves of a retardation in the nucleation frequency. Thus, it is concluded that in a high-purity ternary alloy the nucleation of graphite is not induced by a limited number of nucleating particles, but is of the interfacial ' homogeneous ' variety.

GROWTH RATES OF GRAPHITE NODULES

It is customary to consider the growth of a linear dimension of a precipitate in terms of an equation of the form

$$r = \text{const.} \times t^x \quad \ldots\ldots(4)$$

where x is a constant, t the time, and r the linear dimension. In the present case, r is the radius of the spherical graphite precipitate and the origin is chosen so that when $t = 0$, $r = 0$.

Zener[8] has shown that in the case of a spherical precipitate, growing in a solid solution of infinite extent, the index x has a value of $\frac{1}{2}$. Earlier, Wagner[9] had assumed this value of x in his analysis of the kinetics of moving interfaces in a number of practical cases. The diffusion distance L is given by

$$L = \pi\sqrt{(Dt)} \quad \ldots\ldots(5)$$

where D is the diffusion coefficient.

A number of cases have been reported where L must be considered a constant independent of time.[10] It was found that this assumption was necessary when deriving an empirical equation to describe the overall graphitization reaction,[1] requiring the value of x in equation (4) to be unity.

To distinguish between the two possible values of x the radial growth rate was measured with greater precision than in the earlier work.

The diameter v. time plots at four different temperatures are shown in Fig. 3. For purposes of comparison, they have all been corrected so that growth is shown as starting at zero time, which is the time at the end of the incubation period as revealed by the dilation curves. Since the method of measurement depends upon finding the diameter of the largest graphite nodule present at time t by examining a large number of nodule areas on a number of random planes, the points plotted represent the maximum

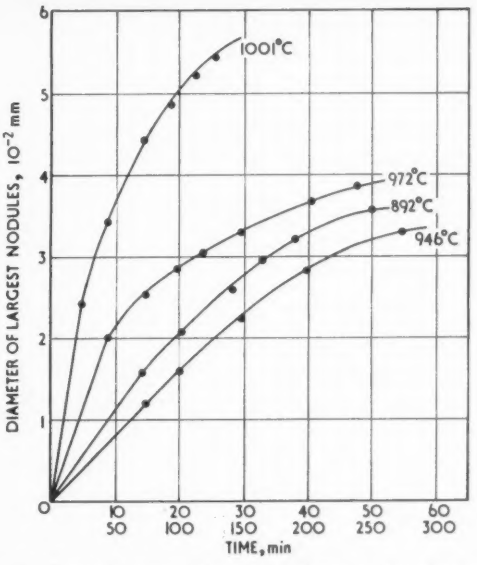


Fig. 3—Growth curves (the longer times on the abscissa refer only to the specimen graphitized at 892° C)

nodule diameter found and are not average readings. Furthermore, the curves have been drawn so that the diameter errors are all negative.

The plots in Fig. 3 deviate from linearity as the reaction proceeds. The index x becomes less than unity and appears to decrease progressively; this suggests that the diffusion distance L starts to increase with time. However, it is not possible to analyse the later portion of the curve in greater detail since this is the time interval in which the largest nodules grow by drawing carbon not only from the remnants of cementite, but also from redissolving small nodules.

The reason for the apparent constant diffusion distance in the early part of the reaction is not clear. Two factors, not considered by Wagner and Zener, can be suggested to account for the observation that the value of x is nearer to unity than to $\frac{1}{2}$. The graphite nodules first appear at the austenite/cementite interface. As the cementite dissolves, this interface moves away from the graphite, but one radial direction of the graphite growth will be towards the cementite and so the separation of the two surfaces will not be very rapid. This situation will certainly alter the characteristics of the diffusion gradients of the intervening austenite. Thus, the real situation appears as a difficult problem involving two moving interfaces which are not equally spaced around the circumference of the nodule. Towards the end of the reaction, when the amount of cementite present is small and remote from the graphite, the situation will more nearly approximate to that of Zener. Secondly, the variation of the degree of supersaturation of carbon with the radius of the nodule will be reflected in the growth rate.

RATE OF SOLUTION OF CEMENTITE

From the measurements of volume percentage of cementite with time the fraction transformation

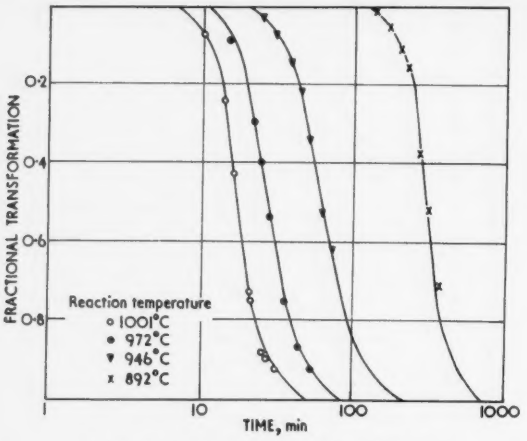


Fig. 4—Rate of cementite solution

curves for the cementite solution reaction were constructed. These are shown in Fig. 4. The data are adequately summarized by an equation of the form

$$y = 1 - \exp\left(-\frac{t}{k}\right)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where y is the fraction dissolved in time t, k is a temperature-dependent rate constant, and n is a constant.

Linear plots were obtained when log log 1/(1–y) was plotted against log t. The activation energy was calculated to be 78,000 cal/mole, which is a little greater than the activation energy for growth of graphite (63,000 cal/mole).

In Fig. 5 the overall reaction-rate curve as determined dilatometrically, and the change of volume fraction of graphite and the reciprocal of the volume fraction of cementite, both determined by microscopic lineal analysis, are plotted on the same graph. This demonstrates two points. Firstly, the volume change measured dilatometrically is a satisfactory measure of the rate of graphitization: i.e. the volume expansion due to the cementite is negligible compared with that due to the formation of graphite. Secondly, over most of the reaction the solution of cementite keeps pace with the formation of graphite.

GENERAL DISCUSSION

It is now possible to suggest in detail the sequence of events which occur during the isothermal growth of a graphite nodule in iron–carbon–silicon alloys. The growth life passes through a number of periods:

(1) Berman[11] has suggested that in the period between the first formation of a graphite nucleus at an austenite cementite interface and its encirclement with austenite (which seems to occur soon after it reaches microscopic dimensions) the graphite nodule grows very rapidly, since it can draw carbon directly from the cementite along the interface and from the austenite

(2) The rate of radial growth is approximately constant. The diffusion distance L remains approximately constant. Towards the end of this period, it is noticeable that although the solution of the neighbouring cementite is incomplete, that which is more remote has also started to dissolve

(3) The rate of radial growth progressively decreases. The diffusion distance L increased continuously and even the most distant carbide starts to dissolve

(4) The carbon level remains constant. All the cementite has disappeared. The nodule either grows or dissolves, depending on whether the neighbouring nodules are smaller or larger. The rate of this transformation decreases with increasing time.

The general features of nucleation are determined by the same environmental conditions as those which affect the growth. Consequently, nucleation is conveniently considered in terms of related periods:

(1) The incubation period and the period before any nuclei have grown to microscopic size

(2) The number of nuclei per unit volume increases linearly and the nucleation frequency per unit interfacial area increases steeply with time. During this time, the predominant growth feature is that of growth period (2)

(3) Nucleation stops. This occurs at the onset of the third growth period in depleted austenite where any nuclei formed are of subcritical size when surrounded by austenite so that they re-dissolve. Since graphitization is a microscopically discontinuous process (i.e. the formation of depleted austenite regions does not occur simultaneously throughout the specimen) there will be no abrupt changeover from periods (2) to (3)

(4) When re-solution of graphite nodules occur, in effect the nucleation frequency is negative; this period overlaps the second and third periods. This results in a negative deviation in the N_v/t curves, and in some cases the curves contain a maximum.

There are too many factors involved to attempt a prediction of the temperature dependence of the changeover point; the experimental curves indicate that at low annealing temperatures the transition is very gradual, and the extent to which the effects of periods (3) and (4) are operative is very small. At higher annealing temperatures, the transition is clearly marked. However, even in the cases where period (4) effects are pronounced, period (1) predominates to about 70% reaction.

During the early part of the reaction, the rate-controlling mechanism is the transfer of carbon atoms across the graphite/austenite interface. The fact that progressively more remote carbide particles start to dissolve before the nearer ones have disappeared suggests that the solution of unit volume of cementite

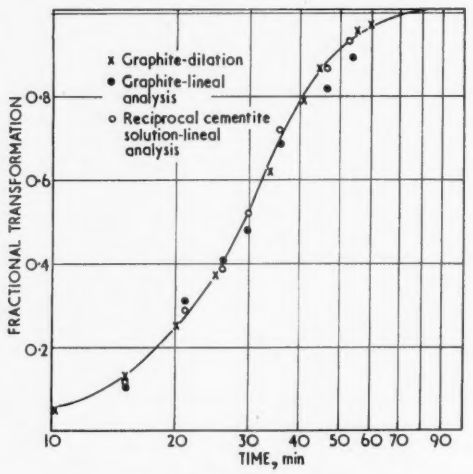


Fig. 5—Reaction curves

is a somewhat slower process than the growth of graphite. However, there is sufficient excess of cementite present during the early stages of the reaction to maintain the supply of carbon. It is not until the volume of cementite remaining is small that the cementite solution mechanism can start to exercise a control over the whole reaction. This control may be operative towards the end, but if it is, its effect is overshadowed by the re-solution of small graphite nodules.

The homogeneous nature of the interfacial nucleation process indicates that austenite/cementite interfacial energy is an important term in the expression for the free energy required to form a graphite nucleus. This suggests that modification of this energy by the presence of impurity atoms in the boundary (but not in the form of a precipitate) may offer a clue to the explanation of some of the mystifying graphitization effects which are encountered in commercial steels and cast irons.

Acknowledgments

This investigation was carried out in the Department of Metallurgy, University of Liverpool. The authors wish to thank Professor E. C. Rollason, their colleagues, Mr. H. Morrogh, Dr. A. Berman, and Dr. J. Burke for their interest and helpful discussions; and the British Cast Iron Research Association for analysis of the alloys. One of the authors (J. W.) held a University of Liverpool Studentship and also received financial assistance from the Andrew Carnegie Research Fund.

References

1. J. Burke and W. S. Owen: *J. Iron Steel Inst.*, 1954, vol. 176, pp. 147–155.
2. C. S. Smith and L. Guttman: *J. Met.*, 1952, vol. 4, Feb., p. 150.
3. R. T. Howard and M. Cohen: *Metals Technology*, 1947, vol. 14, Tech. Publ. 2215.
4. B. F. Brown and M. F. Hawkes: *Trans. Amer. Found. Soc.*, 1951, vol. 59, pp. 181–200.
5. B. F. Brown: *J. Iron Steel Inst.*, 1954, vol. 177, p. 449.
6. W. D. McMillan: *Trans. Amer. Found. Soc.*, 1942, vol. 50, pp. 30–38.
7. M. Avrami: *J. Chem. Phys.* 1939, vol. 7, p. 1103.
8. C. Zener: *J. Appl. Phys.*, 1949, vol. 20, pp. 950–953.
9. C. Wagner: Reported in W. Jost: "Diffusion und Chemische Reaktion in Festen Stoffen": 1937, Dresden.
10. W. A. Johnson and R. F. Mehl: *Trans. Amer. Inst. Min. Met. Eng.*, 1939, vol. 135, pp. 416–442.
11. A. Berman: Private communication.

[*Note*: This paper deals with the first part of the research programme; the major section, concerning the effects of manganese, sulphur, and their ratio on the kinetics of the graphitization reaction, is approaching completion.]

Corrosion of Iron by Oxygen-Contaminated Sodium

By G. W. Horsley, M.A.(Cantab.)

SYNOPSIS

Study of the interaction of iron with oxygen-contaminated sodium suggests that the corrosion associated with the presence of oxygen in sodium is caused by the formation of a stable double oxide $(Na_2O)_2.FeO$. 1077

OBSERVATIONS on the compatibility of sodium with a large number of constructional materials have shown that even at elevated temperatures, interaction with many of these is negligible.[1] However, the presence in the sodium of impurities (in particular, oxygen) has been shown to aggravate its corrosive nature.[2] A great deal of information is available on the stability of the simple oxides of metals, and the significance of the reaction

Metal + sodium monoxide → sodium + metal oxide

has been fully discussed by a number of authors.[2]

The interaction of sodium monoxide with some metal powders whose simple oxides are less stable than sodium monoxide has been studied by Bunzel and Kohlmeyer.[3] Their results indicate that iron, nickel, cobalt, and molybdenum should react under certain conditions with sodium monoxide according to the equations:

$$3Na_2O + Fe = (Na_2O)_2.FeO + 2Na \quad \ldots\ldots(1)$$
$$3Na_2O + Ni = (Na_2O)_2.NiO + 2Na \quad \ldots\ldots(2)$$
$$3Na_2O + Co = (Na_2O)_2.CoO + 2Na \quad \ldots\ldots(3)$$
$$4Na_2O + Mo = Na_2O.MoO_3 + 6Na \quad \ldots\ldots(4)$$

Kelman, Wilkinson, and Yaggee[2] suggest that the reaction given in equation (1) affords a simple explanation for the mechanism of the corrosion of iron by oxygen-contaminated sodium. However, these investigators offer no experimental evidence to substantiate this hypothesis. In view of the practical significance of this problem in connection with the design and running of liquid-sodium-cooled reactors, effort at Harwell has been directed to the investigation of this corrosion mechanism. Briefly, the work has involved the isolation of the corrosion product and its identification by comparison with compounds prepared by heating mixtures of sodium monoxide and iron powder *in vacuo*.

Manuscript received 20th August, 1954.

Mr. Horsley is a Scientific Officer in the Metallurgy Division of the Atomic Energy Research Establishment, Harwell.

EXPERIMENTAL

Materials

Iron—Spectrographically pure iron* for corrosion studies was in the form of 5-mm dia. rod. Metallographic examination of this material showed the presence of a few oxide inclusions. For the investigation of the compounds formed between iron and sodium monoxide *in vacuo*, Swedish iron powder† (−80 mesh) was used. Dead mild steel was employed for obtaining corrosion products in massive form either *in vacuo* or in liquid sodium.

Sodium—Sodium purified by vacuum-distillation in a stainless-steel still was used for the corrosion experiments.[4] Oxygen contamination was effected by the addition of either 'Analar' sodium peroxide or sodium monoxide.

Sodium Monoxide—Sodium monoxide for work on the constitution of mixed oxides of iron and sodium was prepared by heating 'Analar' sodium peroxide in a recrystallized alumina boat *in vacuo* (10μ pressure) at 600–650° C until gas evolution ceased. The product analysed as 99·8% Na_2O. Of the many ways of producing sodium monoxide, this procedure was found to be not only the simplest but also the most efficient.

Procedure

Corrosion Tests—Corrosion studies were carried out in all-welded, electropolished or bright-pickled stainless-steel pots, the design of which is shown in Fig. 1. For the preliminary experiments at low concentrations of oxygen ($< 0{\cdot}5$ wt.-% O_2) these were lined with a thin-walled nickel crucible (0·020 in.), as this metal is little affected by the presence of oxygen in sodium.[2] At high concentrations of oxygen (0·5–10 wt.-% O_2) thick-walled ($\frac{1}{8}$ in.) dead mild steel crucibles were used.

The test pots containing the crucible, the weighed specimen (4 cm × 0·5 cm dia.), and a known amount of oxide contamination were charged with sodium in an atmosphere of purified argon, the operation being carried out in a specially designed stainless-steel chamber. The amount of sodium (about 20 g) was estimated from the level of the liquid metal in the pot. After the coned lids had been rammed into place, the charged containers were removed from the chamber, sealed by argon-arc welding, and heated at 800° C for 7 days.

Isolation and Examination of the Corrosion Product—On removal from the furnace the test pots were allowed to cool in air, the sealing welds were machined off, and the coned lids were removed.

In the early experiments, where the test piece was a bar of iron, the sodium was melted out and the sodium-coated corroded iron specimen was washed in absolute ethyl alcohol until gas evolution ceased. The loosely adherent corrosion product was scraped off into the alcohol, washed by decantation with further quantities of alcohol, and vacuum-dried.

In subsequent experiments at high concentrations of oxygen, where the specimen was in the form of a thick-walled dead mild steel crucible, the test pot was placed in a vacuum furnace immediately after opening and the excess sodium was removed by distillation at 300° C. The corrosion product was then scraped from the sides of the crucible and stored in dry air. Examination of this material was confined to chemical analysis (*see* Appendix) and X-ray powder photographs taken with CoK_α radiation.

Preparation and Examination of Mixed Oxides of Sodium and Iron—Carefully weighed quantities (2–3 g) of sodium monoxide and iron powders mixed in known proportions were placed in an alumina boat and heated to 600° C in an evacuated Vitreosil-tube furnace (10μ pressure.) Sodium vapour produced by the interaction of the two constituents condensed on the cooler parts of the furnace tube. After heating for about 2 h the boat and contents were removed from the furnace and weighed, the final composition of the mixture being inferred from the weight loss.

In a number of experiments the loss in weight of the contents of the boat was compared with the amount of sodium vaporized. The latter, obtained by carefully washing the condensed metal from the walls of the furnace tube with distilled water, was estimated volumetrically.

X-ray powder photographs (CoK_α radiation) of a number of the reaction products were taken for comparison with those of the compound produced by the interaction of sodium monoxide and iron in the presence of liquid sodium.

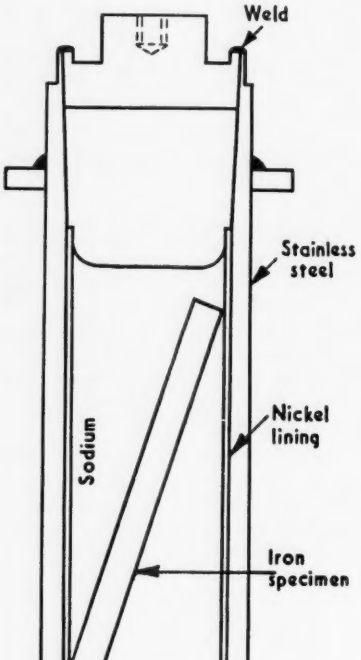


Fig. 1—Stainless-steel test pot (actual size)

* Supplied by Johnson, Matthey and Co., Ltd.
† Obtained from Powder Metallurgy Ltd.

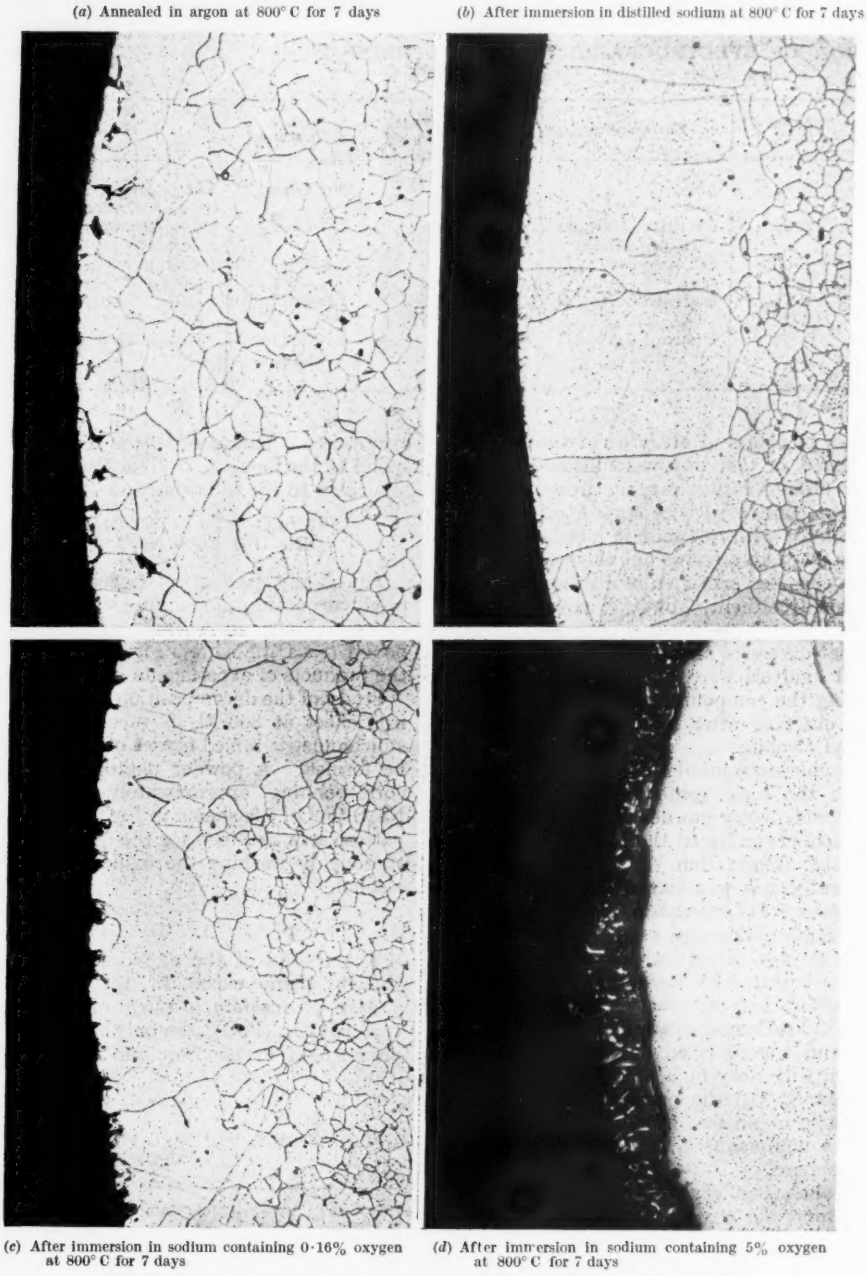

(a) Annealed in argon at 800° C for 7 days
(b) After immersion in distilled sodium at 800° C for 7 days
(c) After immersion in sodium containing 0·16% oxygen at 800° C for 7 days
(d) After immersion in sodium containing 5% oxygen at 800° C for 7 days

Fig. 2—Spectrographically pure iron after various treatments: (*a*)–(*c*) etched in 5% nital, (*d*) unetched × 75

RESULTS

Corrosion of Iron by Oxygen-Contaminated Sodium

The observed effects on spectrographically pure iron after immersion in oxygen-contaminated sodium (up to 0·3% O_2)* at 800° C for 7 days are presented in Table I. These results showed that far higher concentrations of oxygen were required to produce appreciable scaling on the iron. Further experiments were carried out with sodium containing 5% oxygen, and samples treated in this medium suffered extensive corrosion. The brown scale formed was only loosely adherent and could be easily scraped off after the specimens had been freed of sodium by washing in ethyl alcohol.

*The solubility of oxygen in sodium at 800° C is 0·3–0·5 wt.-%.[1]

Table I

INTERACTION OF SPECTROGRAPHICALLY PURE IRON AND OXYGEN-CONTAMINATED SODIUM AT 800° C

Specimen No.	Area, cm^2	Environment	Weight Change, mg/cm^2 per week	Surface Appearance	Structural Changes
1	6·80	Argon	Nil	No change	Very slight peripheral grain-growth (*see* Fig. 2*a*)
2	6·80	Distilled sodium 10 p.p.m. O_2	+0·26	No change	Considerable grain growth in surface layer (*see* Fig. 2*b*)
3	6·62	Sodium 0·07% O_2	−0·69	Etched	Grain growth not as pronounced as in 2
4	6·71	,, ,,	−0·63	,,	
5	5·97	Sodium 0·16% O_2	−8·05	Etched	Surface roughened (*see* Fig. 2*c*)
6	6·74	,, ,,	−8·01	,,	
7	6·75	Sodium 0·3% O_2	−0·4	Etched and stained	Similar to 5 and 6
	6·54	,, ,,	−0·68		

The results of chemical analyses of the corrosion product isolated in this way were inconsistent, the sodium/iron atomic ratios varying from 14·5/1 to 1/4·6. It was considered that scale high in sodium was contaminated with free sodium monoxide and an attempt was made to dissolve out this compound by immersing a corroded specimen in distilled sodium at 800° C. This treatment, however, resulted in the reduction of the scale to iron powder. Further work indicated that excessive amounts of sodium detected by chemical analysis were due to sodium ethoxide contaminating the compound. No high sodium/iron ratios were observed after thorough washing of the scale in ethyl alcohol.

Metallographic examination of corroded specimens showed that the scale contained particles of iron (*see* Fig. 2*d*), and X-ray powder photographs of scale washed in alcohol confirmed the presence of iron but gave no further information. It was concluded that either this substance was formed in an amorphous state or the removal of excess sodium by alcohol broke it down to an amorphous powder.

When the excess sodium surrounding the corroded specimen was removed by low-temperature vacuum-distillation at 300° C, a light-brown corrosion product was obtained. Furthermore, when massive deposits of this compound were formed on iron specimens by using sodium with very high initial oxygen contents (up to 10 wt.-% O_2) the outer layers of the scale contained little or no free iron. The substance appeared to be non-magnetic and rapidly deliquesced in the atmosphere.

Chemical analysis of scales so prepared were again inconsistent and the results were affected by either excess sodium, sodium monoxide, or iron. Fortunately, well defined X-ray powder photographs were obtained of this material (*see* Fig. 3*a*) and comparison with those of reacted sodium-monoxide–iron mixtures showed that by far the largest component of the corrosion product was the double oxide $(Na_2O)_2.FeO$.

Interaction of Sodium Monoxide and Iron *in vacuo*

In Table II are presented the initial molar ratios of the mixtures of iron and sodium monoxide used. The final chemical compositions of the mixtures were inferred from the molar ratios of the original quantity of sodium monoxide to the amounts of sodium metal evaporated. Values of this of 1·50 and 1·00 correspond to the formation of $(Na_2O)_2.FeO$ and $Na_2O.FeO$ according to the following equations:

$$3Na_2O + Fe = (Na_2O)_2.FeO + 2Na$$
$$2Na_2O + Fe = Na_2O.FeO + 2Na.$$

The X-ray powder photographs of the reaction products became more diffuse with increasing amounts of iron. However, clear X-ray pictures of the compound $(Na_2O)_2.FeO$ (*see* Fig. 3*b*) were obtained from the products of experiments 1, 2, and 3 in Table II.

Study of the decomposition of sodium monoxide on iron sheet at 800° C *in vacuo* suggested that non-stoichiometric mixed oxides of iron and sodium could be formed. A powder photograph of a compound corresponding approximately to the composition $Na_2O.(FeO)_{1·6}$ is shown in Fig. 3*c*. The same powder pattern was obtained for the compound produced by thoroughly washing the oxide $(Na_2O)_2.FeO$ in ethyl alcohol.

DISCUSSION

The results of the experiments suggest that, although there exists in the iron–sodium–oxygen system a considerable range of mixed oxides of the type $(Na_2O)_x.(FeO)_y$, the only stable compound in the presence of excess iron and sodium metals is the

Table II

INTERACTION OF Na_2O/Fe MIXTURES AT 600° C *IN VACUO*

Experiment No.	Mole Ratio Na_2O/Fe	Mole Ratio Na_2O/Na (Evaporated)	Final Composition (Inferred from Weight Loss)
1	3·13	1·56	$(Na_2O)_2.FeO$, Na_2O, Fe
2	2·60	1·57	$(Na_2O)_2.FeO$, Na_2O, Fe
3	1·77	1·47	$(Na_2O)_2.FeO$, Fe
4	1·42	1·20	$(Na_2O)_2.FeO$, $Na_2O.FeO$, Fe
5	1·21	1·14	$(Na_2O)_2.FeO$, $Na_2O.FeO$, Fe
6	0·86	1·07	$(Na_2O)_2.FeO$, $Na_2O.FeO$, Fe
7	0·56	1·005	$(Na_2O)_2.FeO$, $Na_2O.FeO$, Fe
8	0·30	1·000	$Na_2O.FeO$, Fe

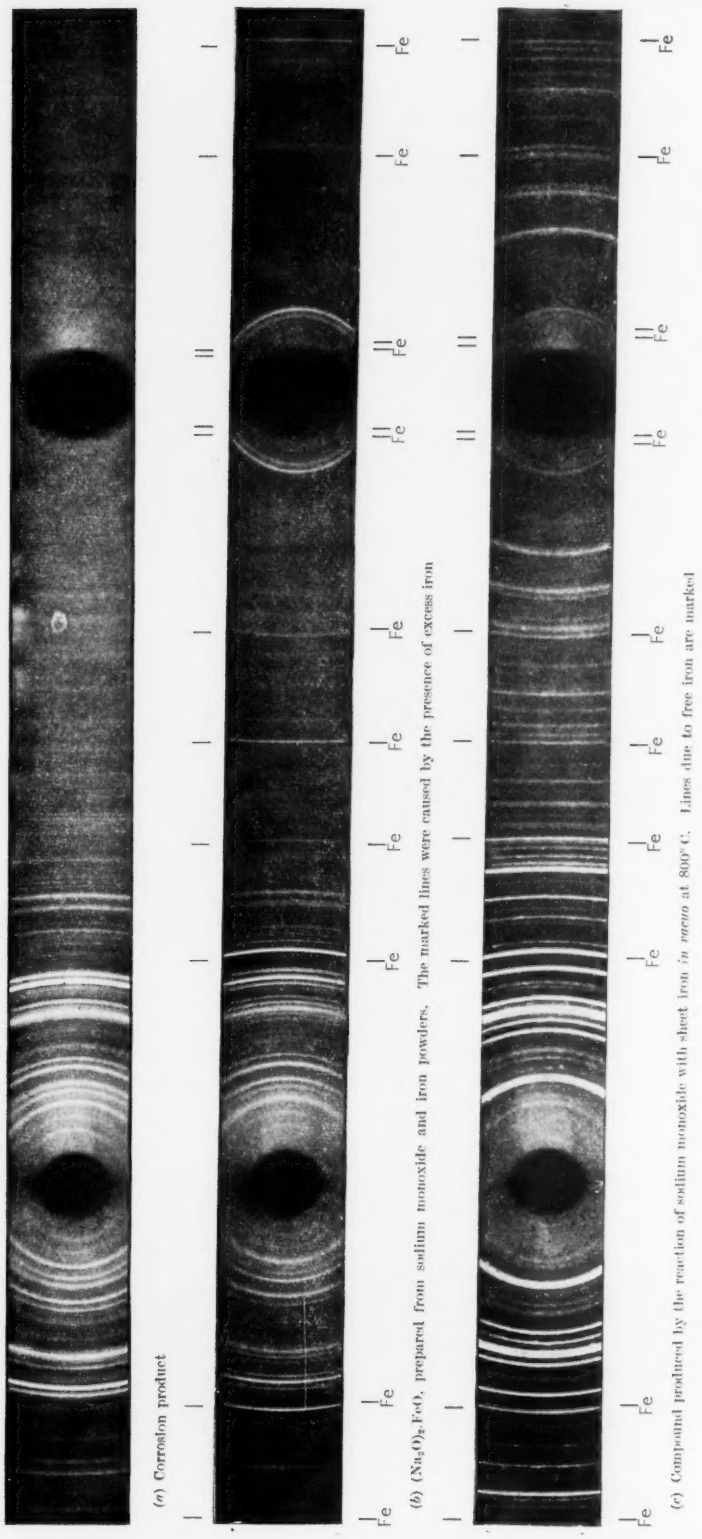

(a) Corrosion product
(b) $(Na_2O)_2.FeO$, prepared from sodium monoxide and iron powders. The marked lines were caused by the presence of excess iron
(c) Compound produced by the reaction of sodium monoxide with sheet iron *in vacuo* at 800° C. Lines due to free iron are marked
Fe

Fig. 3.—Powder photographs

double oxide $(Na_2O)_2.FeO$. It is obvious that those compounds containing the larger proportions of sodium monoxide will be the more difficult to reduce, but no experimental evidence has been obtained of the existence of mixed oxides whose sodium content is greater than that of $(Na_2O)_2.FeO$. If the formation of a double oxide accounts for the corrosion of iron by sodium contaminated with oxygen not only as solid sodium monoxide but also as dissolved oxygen, the data in Table I suggest that a mixed oxide may be stable in sodium containing considerably less oxygen than is required to saturate the metal.

Some of the data presented in Table I appear to be anomalous. Firstly, the small weight gain suffered by the iron specimen immersed in distilled sodium could be accounted for by mass-transfer of nickel from the nickel-containing pot to the iron specimen; such effects have often been observed in many liquid-metal–solid-metal systems. Secondly, there is the apparent decrease of corrosion rate as the oxygen content of the sodium was increased from 0·16% to 0·3%. In these experiments it was observed that particles of the double oxide appeared as a golden incrustation on the surface of the sodium. As no scale was present on the iron specimens it is suggested that the corrosion product was removed from the iron by some solution mechanism, and it is further suggested that such a mechanism would be retarded as the oxygen content of the sodium approached the saturation value (0·3–0·5% at 800° C).[1]

The experiments with the synthetically prepared double oxides showed that the technique of isolating the corrosion product by dissolution of adhering sodium in alcohol could alter both its structure and its composition. It might also be argued that the

removal of excess sodium by low-temperature vacuum-distillation (300° C) could also lead to unreliable results. By arranging conditions so that a large quantity of corrosion product was produced, it was considered unlikely that any change in its structure would result from the precipitation of further quantities of sodium monoxide as the sodium was removed from the system. Since the corrosion product was identified as the oxide $(Na_2O)_2.FeO$ by powder photographs, and since no compound was detected that contained a higher proportion of sodium, it is suggested that there could have been little or no interaction between the scale and iron specimens during the distillation.

As it has been shown that $(Na_2O)_2.FeO$ can be reduced by distilled sodium, it is obvious that the existence of this compound in the presence of sodium is governed by the activity of the oxygen dissolved in the metal. Furthermore, the stability of this compound, in sodium metal containing a given oxygen content, may vary with temperature. If in a closed sodium–iron–oxygen system conditions are such that the effect of thermal cycling results in repetitive formation and reduction of this substance, it is likely that such a mechanism could greatly aggravate normal solution erosion.

To determine whether such a mechanism is possible, a thorough study of the properties of $(Na_2O)_2.FeO$ is required. A measure of its stability in sodium could be obtained by determining the dissolved oxygen in the system Na (*liquid*)–O_2 (*soln.*)–$(Na_2O)_2.FeO$ (*solid*)–Fe (*solid*). A more complete set of data on this system requires the determination of the activity of dissolved oxygen in sodium and the estimation of the free energy of formation of the double oxide.

CONCLUSIONS

(1) The corrosion product formed on iron by oxygen-contaminated sodium is the compound $(Na_2O)_2.FeO$.

(2) The stability of this compound in liquid sodium is governed by the activity of the oxygen dissolved in the metal.

(3) Although mixed oxides can be made containing higher proportions of ferrous oxide than $(Na_2O)_2.FeO$, the greater the iron oxide content the less stable will that compound be in the presence of liquid sodium.

Acknowledgments

The author wishes to thank Dr. P. Murray of Metallurgy Division, A.E.R.E., for his guidance throughout the investigation.

References

1. "Liquid Metals Handbook," NAVEXOS P–733: 1952, Washington, D.C., Atomic Energy Commission, Department of the Navy.
2. L. R. Kelman, W. D. Wilkinson, and F. L. Yaggee: "The Resistance of Materials to Attack by Liquid Metals," Report No. 4417: 1951, Argonne National Laboratory.
3. E. G. Bunzel and E. J. Kohlmeyer: *Zeitschrift für anorganische und allgemeine Chemie*, 1947, vol. 254, pp. 1–30.
4. G. W. Horsley: "The Purification of Sodium by Vacuum Distillation," Atomic Energy Research Establishment Report No. M/R 1152: 1953, London, H.M.S.O.
5. E. B. Sandell: "Chemical Analysis," vol. 3—"Colorimetric Determination of Traces of Metals," 1st ed.: 1944, New York, Interscience Publishers.

APPENDIX

Determination of Sodium and Iron in Mixed Oxides of Sodium and Iron

By M. E. Hocking

In early experiments the ratio of sodium to iron was estimated, the sample weight being unknown. The sample was boiled gently in distilled water to decompose any sodium ferrite present. The solution was filtered and sodium hydroxide in the filtrate was determined by titration with N/10 hydrochloric acid. The residual iron compounds were only partially soluble in hot dilute hydrochloric acid, but dissolved completely on vigorous boiling in more concentrated acid. The two fractions obtained in this way were treated independently for the colorimetric determination of iron using thioglycollic acid.[5]

Later samples were weighed and the actual amounts of sodium and iron present were determined in a similar manner. In these samples the residue dissolved completely in hot dilute hydrochloric acid, leaving only a very small trace of carbon as insoluble matter.

Miss Hocking is an Assistant Experimental Officer in the Analytical Section of the Metallurgy Division of the Atomic Energy Research Establishment, Harwell.

* The figures in parentheses refer to the analysis of a typical sample.

Recommended Procedure

A weighed sample (0·2–0·3 g)* is boiled gently with distilled water (150–200 ml) for about ½ h. The solution is filtered through a Whatman No. 541 filter paper and the residual iron compounds are washed thoroughly with hot distilled water.

Determination of Iron

The residue is dissolved in hot dilute hydrochloric acid and the solution after cooling is made up to a known volume (500 ml). Aliquots (5 ml) are taken for the determination of iron volume (500 ml). Aliquots (5 ml) are taken for the determination of iron colorimetrically with thioglycollic acid.

Determination of Sodium

The combined filtrate and washings are cooled and made up to a known volume (250 ml); suitable aliquots (50 ml) are taken for the determination of sodium hydroxide by titration with N/10 hydrochloric acid using screened methyl orange as indicator. A check for iron is made on a further aliquot of this solution.

The Structural Iron of the Parthenon

By C. J. Livadefs, D.Sc. (Eng.)

SYNOPSIS

This paper deals with an investigation into the metallurgy of the iron used in the erection of the Parthenon. The investigation covers the smelting of iron ore and deals extensively with the iron processes after smelting.

Representative samples of Parthenon iron (two dowels and two clamps) have been studied by metallographic, mechanical, and chemical testing. The paper takes full account of ancient Greek writings dealing with ferrous metallurgy and the work of previous investigators.

The methods of laying the dowels and clamps into the stones and of making the clamps have also been examined.

Finally, a design showing metal processing on an ancient Greek *lekythos* in the British Museum has been studied and interpreted.

1032

Introduction

Origin of Iron in Ancient Greece

AS SHOWN from the texts of extant writings by ancient Greeks, iron was known to them as early as Homer's time.[a] The ancient Greek writers who refer to iron are, in chronological order:

Homer	(840 or 1100 B.C.)
Hesiod	(8th century B.C.)
Herodotus	(484–425 B.C.)
Hippocrates	(460 B.C.)
Plato	(428–348 B.C.)
Aristotle	(384 B.C.)
Theophrastus	(372–287 B.C.)
Aristarchus	(220–143 B.C.)
Diodorus	(90 B.C.)
Strabo	(63 B.C.)
Philo	(20–10 B.C.)
Plutarch	(A.D. 46)

Our knowledge of the mining and origin of the iron ores from which the iron of the ancient Greeks was processed is incomplete, and no detailed reference to the subject is made by any ancient writer (Blumner,[1] vol. 4, p. 206).

According to tradition, the Greeks originally acquired iron and learned of the method of its treatment and use from various peoples of Asia Minor, the Phrygians and Chalybes in particular (Richardson,[2] p. 568). Classics place the cradle of metallurgy in northern Asia Minor, near the Black Sea (Daremberg and Saglio,[3] p. 1084), the area around which was apparently a very ancient metallurgical centre from which the knowledge of metallurgy spread northwards by land and southwards by sea.

This area included the country of the Chalybes, whom Æschylus[b] calls ' workers in iron.' It is difficult to determine accurately the location of that country. In all probability, it extended throughout Pontus, from Trebizond to Erzerum and Kastamoni (i.e. up to Armenia and Paphlagonia) and is described by Herodotus[c] as being inhabited solely and exclusively by metallurgists and blacksmiths. Thence was derived the Greek term *chalyps* for steel.

Ionia, whose merchants travelled in the Black Sea and in the Ægean, gave the first impetus to the propagation of the iron produced in Sinope. Metallurgy was first centred in Miletus, Ephesus, and Samos, and subsequently in Eubœa; early in the 7th century B.C. it spread to other centres such as Corinth, Sicyon, Ægina, and Athens. Shortly afterwards, the exploitation of the iron deposits of Eubœa and Bœotia (Richardson,[2] p. 569) was started.

Although the Greeks of epic times utilized iron to a limited extent, they do not appear to have been acquainted with the method of its reduction from iron ore (Richardson,[2] p. 568). No reference whatever is made to such reduction, in either the *Iliad* or the *Odyssey*, and iron was considered to be a precious[d] metal, little used for making objects. No reference is made to its origin by Homer; in regard to silver, however, he informs us that this came from ' Alybe '[e] which, according to Rangavis (*op. cit.*,[4] p. 69), is ' Chalybe,' in the Caucasus, from which, in his view, the iron of that period also originated in all probability.

Late in the 8th century B.C., Hesiod calls his generation a race of iron[f]; he makes no reference, however, to the origin, mining, or reduction of iron.

Greece, even at the peak of its rise, was never an important producer of iron. Although the Greeks had developed a high degree of skill in the treatment of iron, they imported the major part of their requirements in an unwrought condition. Sparta was perhaps

Manuscript received 17th August, 1954. The translation from the original Greek text was made by Mr. E. K. Mazijoglou.

Dr. Livadefs, formerly Assistant Professor at the Athens Technical University, is now with the Athens Piraeus Electricity Company.

[a] Homer refers to iron 22 times in the *Iliad* and 29 times in the *Odyssey*.

[b] *Prometheus*, 21.

[c] Herodotus, I, 38.

[d] *Iliad*, VI, 48; XI, 23.

[e] *Odyssey*, B, 525: " faraway from Alybe where is the birthplace of silver."

[f] *Works and Days*, 176: " For now truly is a race of iron."

the only exception; the mines of Laconia covered the needs of that city, with, however, a low output. No reference to these mines is made by ancient writers; this can, however, be deduced from the faint traces of works discovered at Tænaron and from the iron-ore deposits in that area, which are covered by rust piles (Daremberg and Saglio,[3] p. 1080).

Laurium also produced iron ore; this, however, was considered to be a negligible item in comparison with the silver-bearing galenite that received all the attention of the miners. Slight traces of operations on iron deposits have also been found in Bœotia, Eubœa (where copper mines also existed, particularly at Chalcis and Ædipsos[g]), and in certain Ægean islands, such as Andros, Syra, Seriphos, and Skyros.

Varieties of Iron Ore Used

No information is available about the iron ores utilized before the 1st century B.C. It may be assumed that the first iron ores were of meteoric origin (Blumner,[1] vol. 4, p. 206). This, however, is contested by Daremberg and Saglio (*op. cit.*,[3] p. 1081), since, firstly, meteorites are rare and, secondly, when these are of a large size, they are difficult to treat: the pure nickel-bearing iron of which meteorites consist (all-iron meteorite) melts at high temperatures and, owing to its extreme hardness, can only be cut by a very hard steel cutting tool. It was therefore practically impossible to make any objects out of meteorites.

Richardson holds the view (*op. cit.*,[2] p. 573) that the primitive technician used meteoric iron. From experiments carried out on such an iron to ascertain whether this iron was readily workable or otherwise, however, he admits that the primitive artificer must have met with great difficulties in the treatment of such iron. A chemical analysis of meteorite, made by Richardson, is reported to have given the following results: Fe, 91·96%; Ni, 7·86%; C, 0·18%.

It is obvious that iron ores, considered by the ancients as richer in iron content, were utilized. The chestnut-coloured hematite (Daremberg and Saglio,[3] p. 1083), with an iron content of about 50%, may be cited as the ore most suitable for the reducing methods of the ancients. It is only in the 1st century B.C. that Diodorus[h] refers to ' siderite earth ' as the iron ore in use. Dioscouridis (A.D. 50) and Pliny (A.D. 23–79) report that magnetite was found in large quantities in Ethiopia, Lydia, Troia, Macedonia, Bœotia, etc. Dioscouridis further refers to *schistus*,[i] which is probably the ' sphærosiderite.' Nowhere, however, in the works of ancient Greek writers is reference made to the method of mining the iron ores (Blumner,[1] vol. 4, p. 209). All that is known is that the mining and reduction of iron ores were carried out in the same place, namely the ' forge.'

Working of Iron by the Ancient Greeks

As early as the Homeric age, the *chalkefs*, as the blacksmith was called, knew that certain heating conditions resulted in the carburization of iron, and that by plunging it into water such red-hot carburized iron was hardened.[j] Empirically, therefore, iron was at that time distinguished from steel (Blumner,[1] vol. 4, p. 212). Homer also calls steel *kyanos*,[k] possibly owing to the blueish colour this product acquires under certain conditions after tempering. Rangavis (*op. cit.*,[5] p. 67), in interpreting the term *kyanos*, says that a certain blue metal by that name was used. In the view of the present author, this is most indefinite. Later Hesiod[l] uses the term *adamas* for steel.

In Homeric times, the use of iron was restricted and it was rarely employed for making weapons. Only once in the *Iliad* is reference made to an iron weapon,[m] namely, to a mace of iron. In the *Odyssey*, moreover, only a limited use of iron is reported for the making of implements. Later on, in the 8th century B.C. and at the time of Hesiod, a certain development is recorded in iron fashioning.

By the end of the 7th century, the simple Homeric methods of working in iron are replaced by a more developed technique and the use of iron is propagated. Thus, during the Olympia excavations, implements were discovered which belong to the period between the 8th and 6th centuries B.C.; these consist of iron nails, spearheads, furniture supports, and tripod rings. Furthermore, at the excavations of Dipylon, in Athens, iron weapons and tools, iron nails, axes, knives, spearheads, and an iron sword (an imitation of the bronze sword) have been discovered, all dating back to the 7th century B.C. It may be assumed with certainty that many offensive weapons of that period were made of iron, or rather of steel (Daremberg and Saglio,[3] p. 1080).

In the 6th century B.C., the technique of iron was perfected. Glaucus the Chian discovered the method of welding iron—according to Herodotus[n] in 560 B.C.

As early as the Archaic period, Attica had a number of forges between Parnis and Æghaleo. In Athens, at the time of Pericles (5th century B.C.), working in iron was practised by resident aliens in the main.[2] Two of the largest known workshops in Greece at that time were devoted to the fashioning of weapons; they were owned by Cephalos and Passius, both aliens. The father of Sophocles was a blacksmith, and the patrimony of Demosthenes comprised a sword workshop. Shields were made in comparatively larger workshops, and it is reported that the father of Lysias owned such a workshop in Piræus, employing 120 slaves, an outstanding industrial undertaking in Attica at the time.[6]

In the 4th century B.C., Laconia produced iron which was used as a medium of exchange in the form

[g] Strabo, X, 447.
[h] Diodorus, V, 13.
[i] Dioscouridis, V, 144.

[j] *Odyssey*, IX, 391: " And as when a smith dips a great axe or an adze in cold water amid long hissing to temper it—for therefrom comes the strength of iron."
[k] *Iliad*, XI, 24.
[l] *Theogony*, 161.
[m] *Iliad*, VII, 144: " Goodly Areithus that men and four-girdled women were wont to call the mace-man, for that he fought not with bow or long spear, but with a mace of iron brake the battalions."
[n] Herodotus, A, 25: " So Alyathes the Lydian, having finished his war with the Milesians, died after a reign of 57 years. He was the second of his family to make an offering to Delphi—and this was a thankoffering for his recovery—of a great silver bowl on a stand of welded iron. This is the most notable among all the offerings at Delphi, and is work of Glaucus the Chian, the only man of that age who discovered how to weld iron."

of spits, from which various weapons and sickles[o] were made.

Later on, in the 1st century B.C., a further advance in iron-working technique emerges. Diodorus[p] reports that, out of iron, blacksmiths "manufacture iron objects of every description." The same writer further describes a practice of steel processing by burying plates of iron in the ground, resulting in the production of a commodity suitable for very powerful swords and other war implements.[q]

Early in the 1st century A.D., iron-working technique records further progress. Philo reports[r] details of the manufacture of very powerful knives from iron surface-hardened by appropriate hammering in the cold state. The whole description demonstrates that the technicians of the period were sufficiently versed in an advanced technique of iron working, and steel grading according to hardness was known. The same writer further reports[s] a method of mechanical testing these knives, which constitutes the first reference to the experimental testing of the strength of materials by Greek writers.

THE STRUCTURAL IRON OF THE PARTHENON

Function of the Structural Iron

The Parthenon was built on the initiative of Pericles. Pentelic marble was used as the material for its erection. Supervision of the whole work was placed in the hands of the sculptor Pheidias, under whom the architect Ictinus and the contractor Callicrates were employed.

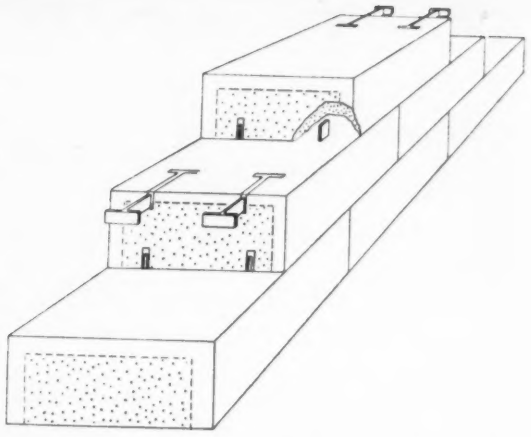


Fig. 1—Dowel and clamp in position in stones

The erection lasted ten years (447–438 B.C.), but the monument, including the work of decoration, was completed by the outbreak of the Peloponnesian War (432 B.C.).

The Pentelic marble blocks used in the erection of the Parthenon are chiselled and are not joined by lime-mortar or any kind of cement. The 'dowel' and the double-**T**-shaped 'clamp' were used to fasten the blocks together. The dowel prevents sliding of two superposed blocks; the clamp prevents displacement of two adjoining blocks, particularly in a direction vertical to the surface of contact. Both the dowels and the clamps consist of iron, which constituted the structural iron of the Parthenon. Figures 1 and 2 show the function of the clamps and dowels. They were in no case visible, owing to their position. Their sizes were proportional to the dimensions of the blocks to be fastened. Figures 3, 4, and 5 give a clear idea of the sizes.

A suitable cavity, called a 'cutting,' was chiselled into the stone to fit into the clamps and the dowels. The clamps were laid into the cavity and lead packing was applied (Figs. 1 and 2); this ensured tight fitting into the stone and prevented oxidation. Furthermore, the lead packing allowed contraction and dilation of the iron without damage to the stone, as the plasticity of the lead eliminated stress to the stone from the expansion or contraction of the clamps.

The dowels were fitted for about half their length in the cavity opened in the underlying stone (Fig. 3). The section thus fitted was well packed with lead which again ensured solid fitting into the stone and prevented oxidation of the dowel. The other half of the dowel, penetrating into the cavity in the overlying stone, could not be secured and packed with lead so well. This explains why, in the blocks from the Parthenon now scattered around the monument, very few complete dowels can be found. The majority of such dowels, including the two specimens examined in the course of the present research, were destroyed

[o] Xenophon, *Hellenica*, III, 3, 7: "'. . . of course those of us who are in the army have weapons of our own, and for the masses.' He led him, he said, to the iron market, and showed him great quantities of knives, swords, spits, axes, hatchets, and sickles."

[p] Diodorus, V, 13: "There are men who purchase such cargoes and who, with the aid of a multitude of artisans in metal whom they have collected, work it further and manufacture iron objects of every description."

[q] Diodorus, V, 33: "For they bury plates of iron in the ground and leave them there until in the course of time the rust has eaten out what is weak in the iron and what is left is only the most unyielding, and of this then they fashion excellent swords and such other objects as pertain to war. The weapon which has been fashioned in the manner described cuts through anything which gets in its way, for no shield or helmet or bow can withstand a blow from it because of the exceptional quality of the iron."

[r] Philo, I, 1: "The reason was therefore sought why they made the knives in this way. They first selected exceedingly pure iron, wrought by fire, free of minute gaps due to bad welding or any other defect; such iron should be neither malleable nor very hard, but something in between. The knives thereby made were subjected to a light cold hammering, for this is what makes them powerful. Such hammering must not be made by means of large hammers and heavy strokes. A heavy and side stroke by hammer destroys the straightness of line of the knife and hardens the metal deeply, so that if one attempts to bend the knives thus hammered, they break, as they do not yield. This is due to the fact that the metal, having been thickened everywhere by hammering, is thick throughout."

[s] Philo, *Mathemat. vett.*, p. 71: "The fashioning of the above blades, in making the so-called Celtic or Spanish knives, has therefore been watched; thus when they wish to test these to see whether they can be used, they hold the knife by the right hand and they lay it on the head in a horizontal position; they then hold the other end with the left hand, press both ends downwards until they touch the shoulders, and they suddenly release both hands. The knife then stops being curved and takes its original straight shape, without manifesting any deformation from bending. This is repeated many times and the knives finally remain straight."

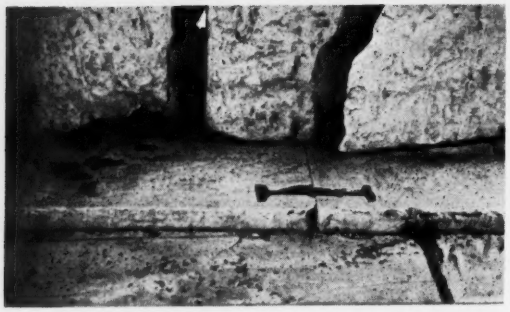


Fig. 2—Photograph of dowel and clamp in position

by oxidation to the extent of half the section not properly packed, which was left without lead coating after the stones were blown up when the explosion occurred in the monument. Details of the method of securing the dowels and clamps within the cavities are given later in the paper.

Joints of stones were made to fit so closely (Penrose,[7] p. 24) that, unless the stones are separated by violence, the joints are not readily detected. In the case of small-sized blocks, the surfaces to be brought into contact were smoothed out by rubbing one stone over the other, as, according to Penrose, it was difficult to achieve this otherwise; in the case of the large blocks (4·5 m long × 0·9 m wide) it is difficult to conceive how this was accomplished. There are some indications of the method of polishing, derived from an inscription discovered which referred to the use of a stone-saw. It is not, however, reported how this was achieved.

Incidentally, the adjoining surfaces of the blocks were not smoothly polished in all their extent, but only along a band of about 10 cm on the upper side and on the vertical sides of the surface in contact, the rest having a moderate degree of roughness. This arrangement was called *anathyrosis* (Fig. 1).

The drums used for the erection of the columns fit perfectly one upon the other. To achieve this, one drum was rubbed upon the other by rotation round a common axis in the two drums. An auxiliary device for such rotation consisted of (*a*) two plugs in the form of a frustum of a pyramid, one plug fitting into the lower middle part of the upper drum and the other into the upper middle part of the lower drum, and of (*b*) a pin in the form of a cylinder—all made of cypress wood.[8]

The plugs were fitted into the centre of the drums and the pin was inserted within suitable round mortises in the plugs and constituted the axis of rotation. After polishing the drums, these plugs and pins were left in the drums, acting as auxiliary clamps, the main fastening being ensured through the weight of the superposed stones.

During the Parthenon restoration work, ten such devices were discovered within the columns, preserved in a comparatively fine condition.

Collection of Specimens

The material for the present research consists of parts of two dowels, *L* and *N*, and of parts of two clamps, *B* and *E*. The parts of dowels *L* and *N* and of clamp *E* were carefully removed (in November, 1942), following authorization from the Administration of the Acropolis Museum, from blocks scattered within the precincts of the Parthenon resulting from the disruption and blowing-up of various structural elements, such as cornice blocks, frieze blocks, architrave blocks, etc., in the 17th century.

Clamp *B*, half broken and thus appearing in the form of a single **T** (Fig. 6), was found within the Parthenon precincts, in the course of the restoration works; it is in excellent condition, and was made available to the writer by courtesy of the Director of the Acropolis Museum, for the purposes of this research. No fragment of clamp or dowel has been removed from the temple, to avoid damage to the monument. Furthermore, the unquestionable origin of the marble blocks round the Parthenon has rendered it unnecessary to remove dowels or clamps from the monument itself.

Beneath their oxidized surface, and to an adequate depth, all the parts are of sound material, a fact which has substantially contributed to the successful issue of this research.

EXPERIMENTAL INVESTIGATION

Scope of Investigation

The experimental research was carried out at the Strength of Materials Laboratory of the Athens Technical University, between November, 1942, and December, 1943. It covered:

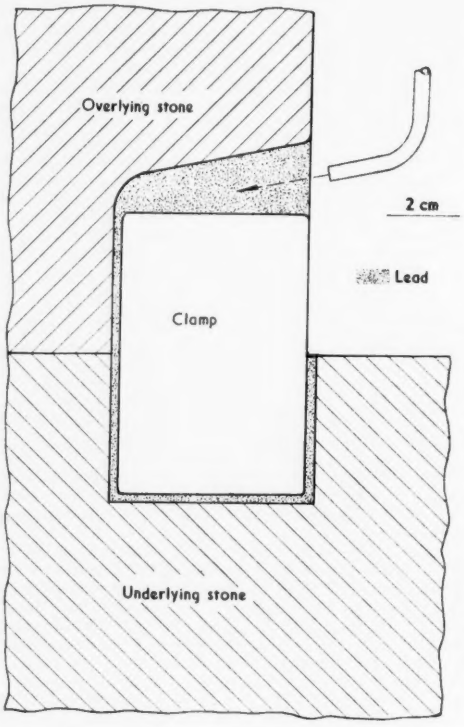


Fig. 3—Dowel position sketch

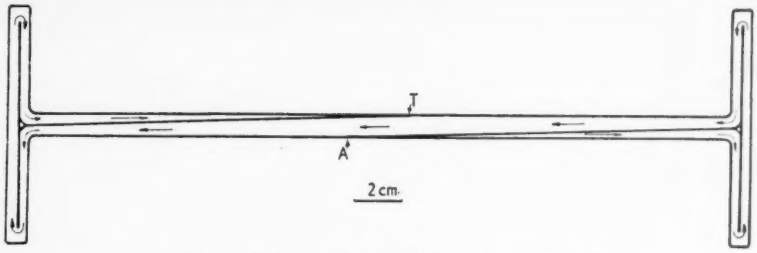


Fig. 4—Method of manufacture of clamp *B*

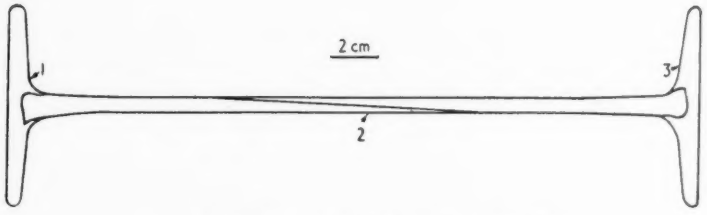


Fig. 5—Method of manufacture of clamp *E*

(i) Metallographic examination of the dowels and clamps
(ii) Testing of the mechanical properties of the material from which the dowels and clamps are made
(iii) Chemical analysis of the material.

Metallographic Examination—This comprised a micrographic examination of the material at various points and a macrographic examination of the cross-sections of the clamps.

For purposes of micrographic examination, the surfaces of the specimens were appropriately polished, in spite of the lack of adequate facilities, and were etched with a 2% solution of nitric acid in alcohol. The examination was conducted under a Le Chatelier microscope.

To illustrate more fully the heterogeneity, both in the size of the crystals in the texture of the various dowels and clamps and in their chemical analysis, successive photomicrographs were taken along axes, and across the thickness of the specimens, such axes being designated a–a_1, b–b_1, etc. These photomicrographs had common segments, and it was therefore possible to assemble them; proper cutting resulted in photomicrographs in the form of bands, covering a photomicrographic surface on the specimens whose area ranged between 3 and 10 mm². The author has not seen this method described in the literature.

For the macrographic examination, the cross-sections of the specimens, which were not polished to the same extent, were exposed to the action of a reagent consisting of a solution of 9% copper ammonium chloride in distilled water. After this treatment, the specimen was washed in abundant water and the etched surface was photographed.

Testing of Mechanical Properties—The only mechanical property which could be measured in all the specimens, which were of very limited sizes and of small thickness, was Brinell hardness. The ball generally used in this test was 10 mm dia., and the load was 1000 or 500 kg, according to the thickness of the specimen.

This permits computation of the U.T.S. by the following approximate formula:

$$S_u = 0{\cdot}36\Delta$$

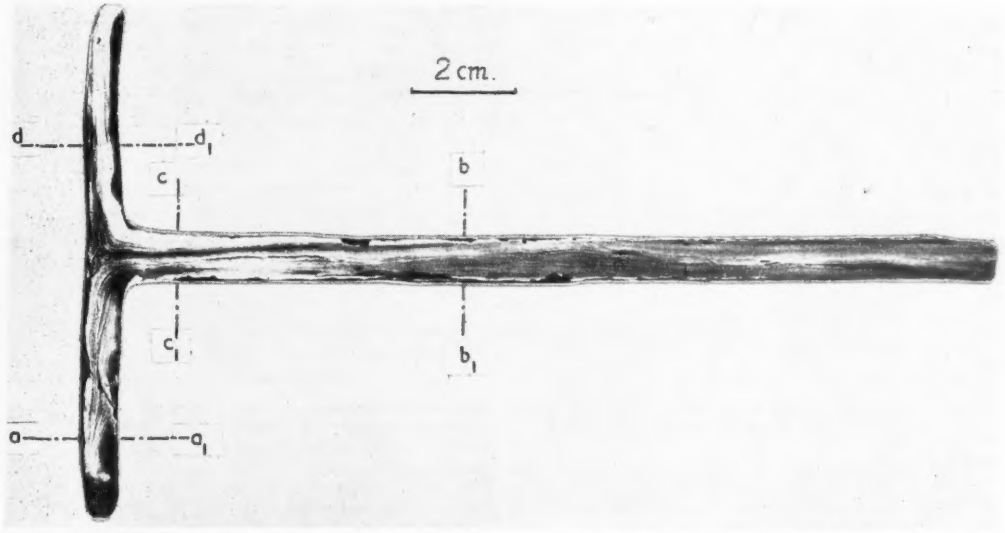


Fig. 6—Photomacrograph of clamp *B*, showing axes along which photomicrographs were taken

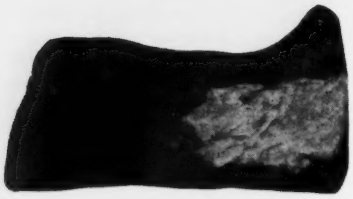


Fig. 7—Fragment of dowel *L*

where S_u = U.T.S., kg/mm²
Δ = Brinell hardness, kg/mm²

This experimental formula applies only to annealed steel.

Unlike the others, the web of clamp *B* supplied two specimens for tensile testing; although small, these were adequate to permit measurement of:

(i) Modulus of elasticity for tension *E*
(ii) Limit of proportionality
(iii) Yield point
(iv) U.T.S.
(v) Elongation.

Chemical Analysis—The chemical analysis of the various specimens, for purposes of determining their carbon, sulphur, phosphorus, silicon, and manganese contents, was carried out at the Analytical Chemistry Laboratory of the Athens Technical University.

Experimental Investigation on Dowel *L*

Dowel *L* had been used to bind a cornice. This cornice was found in the precincts of the Parthenon, southern side. Only a section of the dowel (about one-half) was discovered in the cornice; this section of dowel was preserved in good condition owing to its lead coating. The shape and dimensions of this fragment of dowel are shown in Figs. 7 and 8. The tests on the metal of the dowel cover:

(i) Micrographic examination
(ii) Brinell hardness test
(iii) Chemical analysis.

Micrographic Examination—Figure 8 reproduces the three surfaces of the dowel on which a micrographic examination was made along axes a–a_1, b–b_1, and c–c_1. Figures 9*a*–*c* are photomicrographs of three characteristic bands along axes a–a_1, b–b_1, and c–c_1. Table I gives the size of the crystals, the constituents of the metal, and the slag inclusions in the material.

Brinell Hardness Test—Brinell hardness tests were made at various points on dowel *L*. A 10-mm dia. ball was used and a load of 1000 kg was exerted. The results of these tests are given in Table II, which

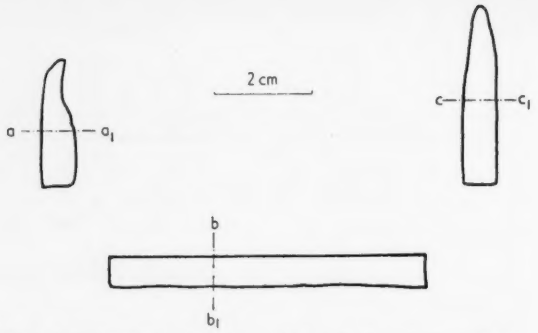


Fig. 8—Drawing showing sides of dowel *L*; photomicrographs were taken along axes indicated

also gives the approximate U.T.S. of the metal, arising from the experimental formula given above.

Chemical Analysis—The results of the chemical analysis of the material removed from various parts of the dowel are given in Table III.

Material of Dowel L—Dowel *L* consists in the main of carbon-free iron, with steel of variable carbon content in places. The carbon content ranges between traces and approx. 0·85%, as revealed by the micrographic examination. The mean carbon content, resulting from the chemical analysis, is 0·163%. Slag inclusions have been detected in adequate measure, spread over the mass of the metal. The metallographic examination of dowel *L* supports the Blumner hypothesis about the method of iron smelting at the time of the ancient Greeks, and about the quality of the resultant product. According to that hypothesis, to which more extensive reference is made in a later section, primitive furnaces supplied a product consisting partly of carbon-free iron and partly of steel of a variable carbon content, with extensive slag inclusions removed by hot hammering.

Heterogeneity in Crystal Grain Size and Method of Fitting Dowels—The fashioning of the dowel caused local alterations both in the size of crystals and in their chemical composition. This dowel was shaped by hot hammering. Finishing cold hammerings caused small crystals to appear at points of hammering; they are shown at the edges of the bands in Figs. 9*a* and *b*.

For such a transformation in the size of the crystals to be manifested, the material must have been reheated to about 900° C. Furthermore, the local carburization detected at certain points of the metal presupposes exposure of the metal in carburized surroundings at about 900° C. The question thus

Table I
MICROGRAPHIC EXAMINATION OF DOWEL *L*

Fig. No.	Axis	Grain Size	Constituents	Slag Inclusions
9*a*	a–a_1	Coarse grains in section 1 become gradually finer towards sections 2 and 3	Ferrite in sections 1 and 2. Steel with carbon content of about 0·05% in section 3	Few
9*b*	b–b_1	Coarse grains in section 2 become sharply finer towards sections 1 and 3. Fine grains in section 4 and finer grains in section 5	Ferrite in sections 1, 2, and 3. Steel with carbon content of about 0·85% in section 4. Carburized steel with carbon content of about 0·45% in section 5	Few
9*c*	c–c_1	Coarse grains throughout the band	Ferrite throughout the band	Abundant

Table II

BRINELL HARDNESS AND U.T.S. OF DOWEL *L*

Point	Hardness Δ, kg/mm²	U.T.S. S_u, kg/mm²
1	79	28·4
2	76	27·4
3	68	24·5
4	76	27·4
Av.*	75	27

* The average values correspond to the mechanical properties of carbon-free iron

obviously arises: what were the technical reasons for reheating the dowel? The explanation lies in the method of laying the dowel into the cavity.

The fitting of the dowels into the cavities in the underlying stones impresses the observer for the solidity of the packing and the comparative thinness of the lead surrounding the dowels. The lead was poured into the cavities in molten condition (m.p. of lead = 327° C). This method of fitting is especially apparent at the eastern side of the Parthenon portico, on the walls of which, in places where the stones are broken, the smooth surfaces of the layers of lead surrounding the dowels and clamps are detected. Into such a cavity in the underlying block, already filled with molten lead, the dowel was plunged to half its length, after prior heating to about 900° C; it has been ascertained by the author that this is the lowest temperature at which, under normal daylight conditions, adequate heating of iron for the purpose can be detected outdoors in Athens. This process of submerging the dowel caused the molten lead to overflow and the fit was perfect, restricting the thickness of the surrounding lead to the practicable minimum.

Experiments carried out by the author have demonstrated that this process of dowel fitting is the best. Laying a cold dowel into the molten lead does not, owing to the sudden cooling of the lead, provide a close fit; only a loose fit is ensured, the iron being liable to displacement.

Accordingly, the section of the dowel penetrating into the overlying stone did not fit in equally well, as in that case the lead was poured over the cold protruding section of the dowel, as shown in Fig. 3.

The reheating for these reasons gave rise to local carburization of the dowel material, since it was exposed in carburizing surroundings at 900° C.

These local carburizations are strong in certain places, owing to the simultaneous action of charcoal powder, when in contact with the metal and CO; in others they are weak, owing to the action of CO alone, as shown in section 4 of Fig. 9*b*. These carburizations in general do not appear to have penetrated to a great depth, but are superficial, because the material was not exposed for long to a carburizing temperature.

Table III

CHEMICAL COMPOSITION OF CLAMPS AND DOWELS

	C, %	S, %	Si, %	P, %	Mn, %
Dowel *L*	0·163	0·014	0·046	0·023	Nil
Dowel *N*	0·395	0·008	0·043	0·024	Nil
Clamp *B*					
Flange	0·419	0·016	0·055	0·032	Nil
Web	0·117	0·006	0·056	0·008	Nil
Clamp *E*					
Flange	0·104	0·006	0·061	0·012	Nil
Web	0·350	0·007	0·065	0·006	Nil

Experimental Investigation on Dowel *N*

Dowel *N* was used to hold in position an overlying stone on an underlying stone. The underlying stone, within which the section (about one-half of the original size) of dowel *N* under research was packed, was found within the precincts of the Parthenon, north-western side. The efficient lead coating of the dowel has preserved the metal in good condition. The shape and dimensions of this fragment of dowel are shown in Figs. 10 and 11. The research into the metal of the dowel covers:

(i) Micrographic examination
(ii) Brinell hardness test
(iii) Chemical analysis.

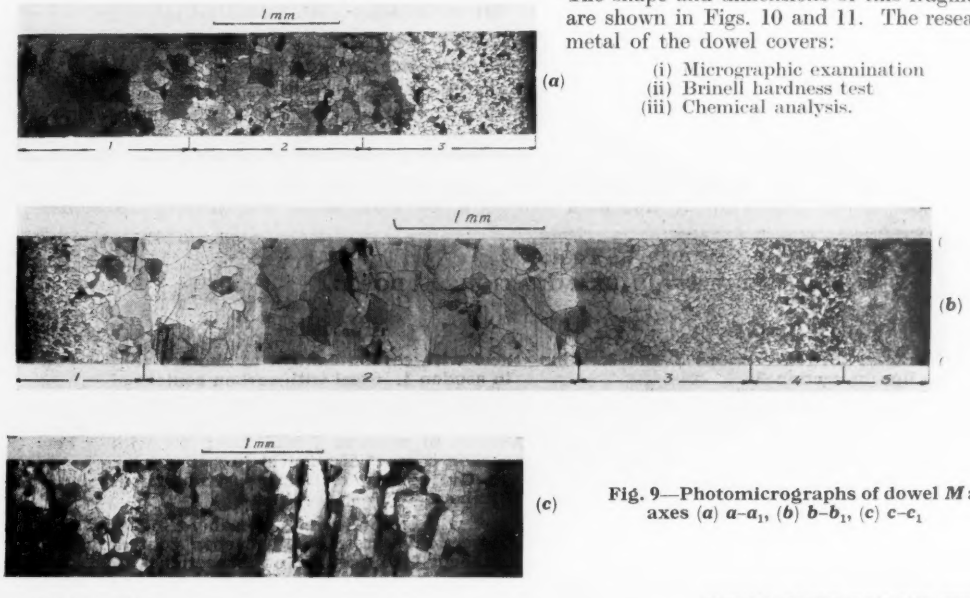


Fig. 9—Photomicrographs of dowel *M* along axes (*a*) *a*–a_1, (*b*) *b*–b_1, (*c*) *c*–c_1

Fig. 10—Fragment of dowel *N*

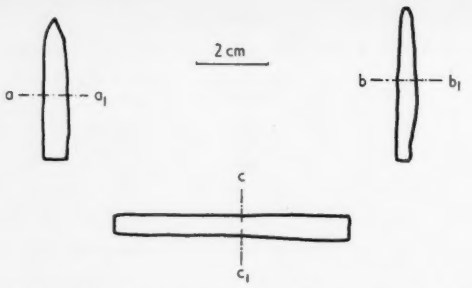


Fig. 11—Drawing showing sides of dowel *N*; photomicrographs were taken along axes indicated

Micrographic Examination—Figure 11 shows the three surfaces of the dowel, of which a micrographic examination was made along axes a–a_1, b–b_1, and c–c_1. Figures 12*a*–*c* are micrographs of three characteristic bands along axes a–a_1, b–b_1, and c–c_1. Table IV gives the grain size of the crystals, the constituents of the metal, and the slag inclusions in the material.

Brinell Hardness Test—This test covered various points on the dowel. A 10-mm dia. ball was used, with a load of 1000 kg.

The results of these tests are set out on Table V, which also shows the approximate tensile strength S_u of the metal, derived from the hardness Δ.

Chemical Analysis—The results of the chemical analysis of the metal, taken from various spots of the dowel, are given in Table III.

Material of Dowel N *and Method of Fitting*—Dowel *N* consists partly of carbon-free iron and partly of steel of variable carbon content ranging between traces and 0·9%, with slag inclusions. The mean carbon content from the chemical analysis is 0·395%. A metallographic test supports Blumner's hypothesis about the smelting process of the iron and the quality of the resultant product.

Dowel *N* appears to have been shaped by hot hammering. The treatment before shaping and also the method by which it was packed into the cavity are in all respects similar to those used on dowel *L*, and these have caused alterations in both the chemical composition of the crystals and their grain size.

The heating of the dowel before shaping, probably by charcoal, lacked uniformity. Exposure to a high temperature up to the critical point t (= 900° C) appears to have been long enough to render the steel fine-grained, as shown by the photomicrographs.

The unusually large ferrite crystals shown at certain end sections of the dowel (Fig. 11*b*) are due to a local hardening of the material, caused by finishing cold hammerings at the time of shaping. The fact that these crystals are now revealed demonstrates that the dowel was reheated before being plunged into the molten lead, as reported in the case of dowel *L*.

Keeping the dowel at 900° C in the process of reheating led to local carburization, as shown on the right-hand sections of Figs. 12*b* and *c*. Such carburization occurred as a result of the simultaneous action of the charcoal powder, in contact with the metal, and CO, and is nearly superficial owing to the non-exposure of the metal to an adequately carburizing environment. Charcoal was probably used for heating the metal.

Experimental Investigation on Clamp *B*

This clamp was double-**T**-shaped and served to fasten together two adjacent stones. The fragment found is half of the original clamp and is thus single-**T**-shaped.

Figure 4 is a front view of the clamp, which is approximately 25 mm wide. The research on the metal of this clamp covers:

(i) Micrographic examination
(ii) Macrographic examination
(iii) Determination of mechanical properties
(iv) Chemical analysis.

Micrographic Examination—Figure 6 is a macrophotograph of the clamp and shows the points at which micrographic examination was made along axes a–a_1, b–b_1, c–c_1, and d–d_1. Figures 13*a*–*d* are photomicrographs along axes a–a_1, b–b_1, c–c_1, and d–d_1. Table VI gives the grain size of the crystals, the constituents of the metal, and the slag inclusions.

Table IV
MICROGRAPHIC EXAMINATION OF DOWEL *N*

Fig. No.	Axis	Grain Size	Constituents	Slag Inclusions
12*a*	a–a_1	Coarse grains in sections 1 and 3. Fine grains in section 2	Steel with carbon content of about 0·13% in section 1. Steel with carbon content of about 0·20% in section 2. Ferrite in section 3	Few
12*b*	b–b_1	Unusually coarse grains in section 1. Coarse and fine grains, alternately, in sections 2, 3, and 4	Ferrite in sections 1 and 2. Steel with carbon content of about 0·10% in section 3. Overheated steel with carbon content of about 0·50% in section 4	Few
12*c*	c–c_1	Fine grains throughout the band	Steel with carbon content of about 0·20% in section 1. Steel with carbon content of about 0·50% in the other sections	Few

Table V

BRINELL HARDNESS AND U.T.S. OF DOWEL *N*

Point	Hardness Δ, kg/mm²	U.T.S. S_u, kg/mm²
1	88	31·68
2	166	59·76
3	154	55·44
4	134	48·24
5	92	33·12
Max.*	166	59·76
Min.†	88	31·68

* These values correspond to the mechanical properties of steel with a carbon content of about 0·5%

† These values correspond to the mechanical properties of carbon-free iron

Macrographic Examination—For macrographic examination, the surface of the clamp was appropriately polished and subsequently exposed to the action of a reagent; the photomacrograph shown in Fig. 6 was then taken, which shows the method by which the clamp was made.

To make clamp *B*, a strip of metal approx. 25 mm wide × 4 mm thick was refolded and hammered in a suitably heated condition, to ensure welding of the sections refolded. Figure 4 shows this process of refolding. One end of the strip is marked *A*, and the other end is marked *T*. This strip was overheated at certain points, as shown by micrographic examination.

Support for this suggested method of making the clamp is given by the way in which tensile test specimens, taken from the web of the clamp, were broken. In the course of the test, the specimens broke off into the component strips which had not been effectively welded, and fell apart.

This method of manufacture requires a more advanced technique than another possible process, described below. Metal welding was widely known before the time the Parthenon was built, but it was not always successful.

Determination of Mechanical Properties—It was possible to take two specimens from clamp *B* for tensile testing, to determine the mechanical properties of the material. These specimens (I and II) were from the web of the clamp. The dimensions of the specimens were not in accordance with the requirements of standard specifications for tensile testing, owing to lack of sufficient material. The tests were made on an Amsler-type tensile testing machine. Micro-measurements were made with a Huggenberger tensometer, recording deformations to 1 micron. On the basis of the measurements of deformation and of the corresponding loads, stress/strain graphs were plotted, which gave values for the limit of proportionality and the yield point.

Table VII gives the results of the measurements taken. In this Table*

F_0 = Area of original cross-section of tensile specimen

E = Modulus of elasticity for tension

$$\text{Elongation} = \frac{l - l_0}{l_0} \times 100$$

where $l_0 = 5{\cdot}63\sqrt{F_0}$ = Original length according to Swiss Standard Specifications (short specimen)

l = Final length.

Specimen I was almost homogeneous; it was thus also possible to find the modulus of elasticity for tension of this material (19,200 kg/mm²). Furthermore, fracture normally occurred which permitted measurement of the elongation (18·8%). The material

* To determine the limit of proportionality, a permanent set equal to 0·005% was taken as a basis. In the case of the yield point, the permanent set taken as a basis was 0·2% (Swiss Standard Specifications, 1935).

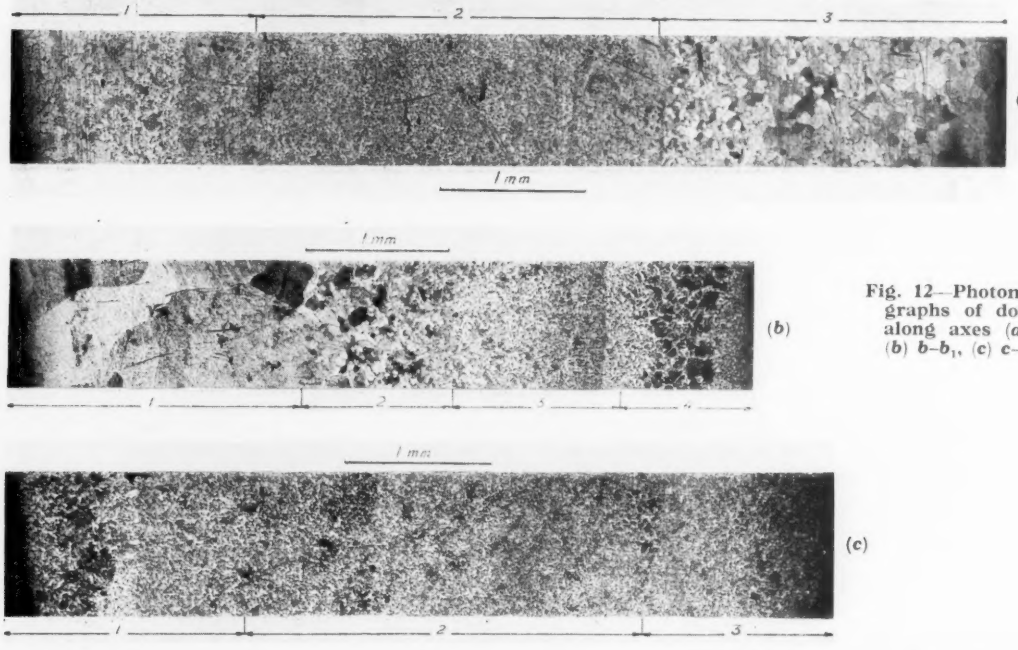


Fig. 12—Photomicrographs of dowel *N* along axes (*a*) *a*–a_1, (*b*) *b*–b_1, (*c*) *c*–c_1

Table VI

MICROGRAPHIC EXAMINATION OF CLAMP *B*

Fig. No.	Axis	Grain Size	Constituents	Slag Inclusions
13*a*	a–a_1	Coarse grains in section 1. Coarse grains in section 2 become finer towards the end	Overheated steel with carbon content of about 0·4% in section 1. Tempered steel in section 2	None
13*b*	b–b_1	Fine grains in section 1 become gradually finer towards the sections 2 and 3	Ferrite in section 1. Steel with carbon content of about 0·30% in section 2. Carburized steel in section 3	Few
13*c*	c–c_1	Coarse grains in sections 1 and 2 become less coarse towards sections 3 and 4	Steel with carbon content of about 0·55% in section 1. Overheated steel with carbon content of about 0·35% in section 3. Ferrite in section 4	Few
13*d*	d–d_1	Alternately coarse and less coarse grains throughout the band	Ferrite throughout 80% of length of the band. Overheated steel with carbon content of about 0·30% over remaining length of the band	Few

of this specimen has the mechanical properties of a more or less carbon-free iron.

Specimen II was found to be heterogeneous, consisting of two strips extending throughout the length of the specimen and a smaller strip incorporated between these two strips. This is due to inadequate welding of the mass of the material, owing to slag intervention on making the clamp from a strip. For this reason, although it was possible to find the limit of proportionality and the yield point of the specimen, the modulus of elasticity for tension of the material could not be ascertained owing to the heterogeneity of the specimen. Furthermore, the U.T.S. (43 kg/mm²) refers to the material of only the thicker of

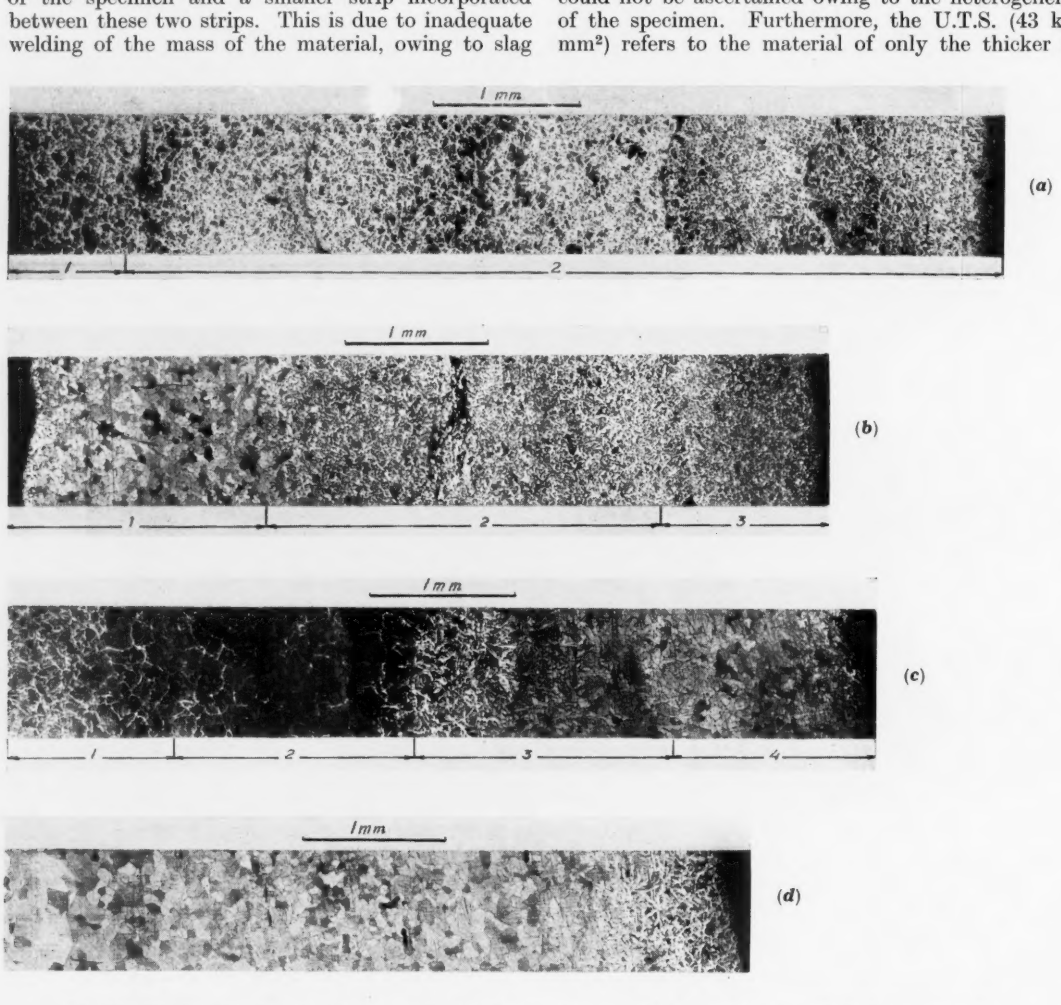


Fig. 13—Photomicrographs of clamp *B* along axes (*a*) a–a_1, (*b*) b–b_1, (*c*) c–c_1, (*d*) d–d_1 (*see* Fig. 6)

Table VII

TENSILE PROPERTIES OF CLAMP *B*

Specimen	F_o, mm²	*E*, kg/mm²	Limit of Proportionality, kg/mm²	Yield Point, kg/mm²	U.T.S., kg/mm²	Elongation, %
I	43·3	19,200	17·6	19·3	30·7	18·8
II	42·3	...	18·8	19·4	43*	...

* From cross-section F_o = 24·5 mm²

the two strips. This strip broke under a load of 1050 kg, the other strip having fallen apart under a lower load.

The material of specimen II has the mechanical properties of low-carbon steel.

Brinell Hardness Test—The hardness tests were carried out at various points on the web and flange of the clamp. In general, a ball of 10 mm dia. was used. The load on the flange was 1000 kg; a 500-kg load was used on the web, owing to its inadequate thickness. The results of these tests are given in Table VIII.

Chemical Analysis—The results of the chemical analysis of the metal taken from various points on the flange and the web of the clamp are given in Table III.

Material of Clamp B *and Method of Fitting*—This material consists partly of carbon-free iron and partly of steel whose carbon content ranges between traces and 0·9%. The mean carbon content of the metal from the chemical analysis is, in the case of the flange, 0·419%, and, in the case of the web, 0·117%. The higher carbon content in the flange is explained by the fact that the strip refolded to form the flange (Fig. 4) was locally richer in steel, as shown by the hardness-test results on the flange (Table VIII). Slag inclusions are spread throughout the mass of the metal. The micrographic examination supports the hypothesis of Blumner about the iron-smelting process practised by the ancient Greeks.

The clamps were fitted into the stones in a most effective way, and the comparatively thin lead coating of the clamps covers them fully. To achieve such effective packing, the molten lead was poured into the cavity and the clamp was subsequently laid in it after reheating at about 900° C, as for the dowels. The heated clamp, held with tongs, was plunged into the molten lead, which overflowed, ensuring faultless fitting of the clamp; the thickness of the surrounding lead could thus be reduced to the minimum limit practicable. Where the cold tongs held the heated metal a local tempering took place, as shown by the existence of troostite, ascertained in the course of the micrographic examination of the flange of the clamp, along axis a–a_1 (Fig. 13*a*). Such a tempering was also detected by Campbell and Thum (*op. cit.*,[9] p. 94) in the course of research on a clamp from the Parthenon.

The small ferrite grains detected at certain edges of the clamp are due to a local hardening caused by cold hammering and were produced, as in the case of the dowels, by the reheating.

Experimental Investigation on Clamp *E*

Clamp *E*, in the form of a double-**T**, was used to fasten two adjacent stones. The stone carrying half of this clamp, on which the present research was conducted, was found within the precincts of the Parthenon, at its northern side. The other half of the clamp remained in the stone after fracture.

Table VIII

BRINELL HARDNESS OF CLAMP *B*

Web					Flange		
Points	Front View		Back View		Points	Δ, kg/mm²	S_u, kg/mm²
	Δ, kg/mm²	S_u, kg/mm²	Δ, kg/mm²	S_u, kg/mm²			
	Specimen I						
1	99·2	35·7	118	42·5	1	131	47·2
2	98·7	35·2	...	...	2	140	50·4
3	98·4	35·4	...	...	3	85	30·6
4	87·4	31·5	116	41·8	4	89	32·0
					5	98	35·3
	Specimen II						
1	101	36·4	156	56·2			
2	113	40·7	158	56·9			
3	114	41·0	...	...			
4	99·2	35·7	...	...			
5	87·4	31·5	235	...			

Flange

Maximum Δ = 140 kg/mm² } These values correspond to the mechanical properties of steel with carbon content of about 0·35%
Maximum S_u = 50·4 „ }

Minimum Δ = 85 kg/mm² } These values correspond to the mechanical properties of carbon-free iron
Minimum S_u = 30·6 „ }

Web

Maximum Δ = 235 kg/mm² — This value corresponds to the mechanical properties of high-carbon steel

Minimum Δ = 87·4 kg/mm² } These values correspond to the mechanical properties of carbon-free iron
Minimum S_u = 31·5 „ }

Table IX

MICROGRAPHIC EXAMINATION OF CLAMP *E*

Fig. No.	Axis	Grain Size	Constituents	Slag Inclusions
15*a*	a–a_1	Uniform grains throughout the band	Ferrite throughout the band	Abundant
15*b*	b–b_1	Fine grains in sections 1 and 3. Coarse grains in sections 2 and 4	Steel with carbon content of about 0·20% in section 1. Overheated steel with carbon content of about 0·45% in section 2. Tempered steel in section 3 (troostite). Overheated steel in section 4	Few
15*c*	c–c_1	Very fine grains throughout the band	Steel with carbon content of about 0·10% throughout the band	Few
15*d*	d–d_1	Fine grains in section 1. Coarse grains in section 2. Note the gap due to defective welding	Steel with carbon content of about 0·20% in section 1. Overheated steel with carbon content of about 0·45% in section 2	Abundant

As it was not possible to remove the section of the clamp complete without damage to the stone, removal was effected by pieces; hence the clamp is in two fragments (*see* Fig. 14). The clamp is approx. 25 mm wide. The missing part of the flange was left broken in the stone, as it was impossible to remove it.

This clamp was coated with lead, and so the metal was preserved in good condition. The experimental research on the metal of clamp *E* covers

(i) Micrographic examination
(ii) Macrographic examination
(iii) Brinell hardness test
(iv) Chemical analysis.

Micrographic Examination—Figure 14 is a photomacrograph of the clamp, which shows the points at which micrographic examination was made along axes a–a_1, b–b_1, c–c_1, and d–d_1. Figures 15*a*–*d* are photomicrographs taken along these axes, respectively. Table IX gives the grain size of the crystals, the constituents of the metal, and the slag inclusions.

Macrographic Examination—For purposes of macrographic examination, the surface of the clamp to be macrographed was appropriately polished; it was then etched by a reagent and Fig. 14 was taken.

This clamp, as shown in Fig. 5, was made by welding three pieces of metal strip, each approx. 25 mm wide × 8 mm thick. Two pieces (1 and 3) form the two flanges of the double-**T**, and the third piece (2) forms the web of the clamp. As shown by the micrographic examination (Fig. 15*d*), however, piece 2 consisted of two sections welded one in extension of the other.

This method of making the clamp in the form of a double-**T** is entirely different from that described for clamp *B*.

Brinell Hardness Test—Brinell hardness tests were carried out at various points of the flange and the web of the clamp. A 10-mm dia. ball was used and the load was 1000 kg.

The results of these tests are given in Table X, which also gives the U.T.S. of the metal.

Chemical Analysis—The chemical analysis of the metal taken from the flange and the web of the clamp is given in Table III.

Material of Clamp E *and Method of Fitting*—The material of clamp *E* exhibits heterogeneity, both in the composition of the crystals and in their grain size. This clamp consists partly of carbon-free iron and partly of steel of a variable carbon content ranging between traces and 0·9%. The mean carbon content of the metal, derived from the chemical analysis, is in the case of the flange 0·104%, and in that of the web 0·350%. Slag inclusions are spread throughout the mass of the metal. The metallographic examination of the clamp at various points again confirms Blumner's hypothesis about the smelting of iron by the ancient Greeks.

The method of making this clamp, by welding metal strips, has given rise to local alterations both in the size of the crystals and in their chemical composition. Overheating of the metal is observed at certain places,

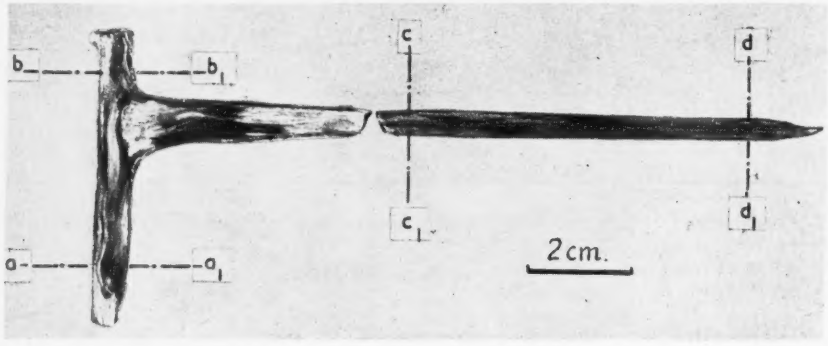


Fig. 14—Photomacrograph of clamp *E*, showing axes along which photomicrographs were taken

and a superficial carburization at others. The clamp was fitted into the stone in the same way as clamp *B*. Also, on clamp *E* a local tempering (troostite) is detected at the right-hand edge of the flange, precisely at the point where this was fractured on removal from the stone. This is due to the gripping of the heated clamp by means of cold tongs so as to lay it into the molten-lead-filled cavity.

The small ferrite crystals to be seen at certain edges of the clamp are due to a local hardening caused by cold hammering. These must have been manifested when the clamp was reheated before it was plunged into the molten lead.

Summary

Quality of the Material—The material making up the Parthenon dowels and clamps examined exhibits heterogeneity in composition. Such material as a rule consists of carbon-free iron in some places and steel with a variable carbon content (ranging between traces and 0·9%) in other places, with slag inclusions.

Chemical Analysis—The chemical analysis of the material of the clamps and dowels examined has given the results summarized in Table III.

Mechanical Properties—Coefficients defining the mechanical properties of the material could not be

Table X

BRINELL HARDNESS OF CLAMP *E*

Flange			Web		
Point	Δ, kg/mm²	S_u, kg/mm²	Point	Δ, kg/mm²	S_u, kg/mm²
1	100	36·00	1	91	32·76
2	96	35·28	2	107	38·52
3	97	34·92	3	122	43·92
4	130	46·80	4	124	44·64
5	91	32·76	5	97	34·92
			6	100	36·00

Flange

Max. Δ = 130 kg/mm² } Steel with C = 0·25% (approx.)
Max. S_u = 46·80 ,,
Min. Δ = 91 ,, } Carbon-free iron
Min. S_u = 32·76 ,,

Web

Max. Δ = 124 kg/mm² } Steel with C = 0·25% (approx.)
Max. S_u = 44·64 ,,
Min. Δ = 91 ,, } Carbon-free iron
Min. S_u = 32·76 ,,

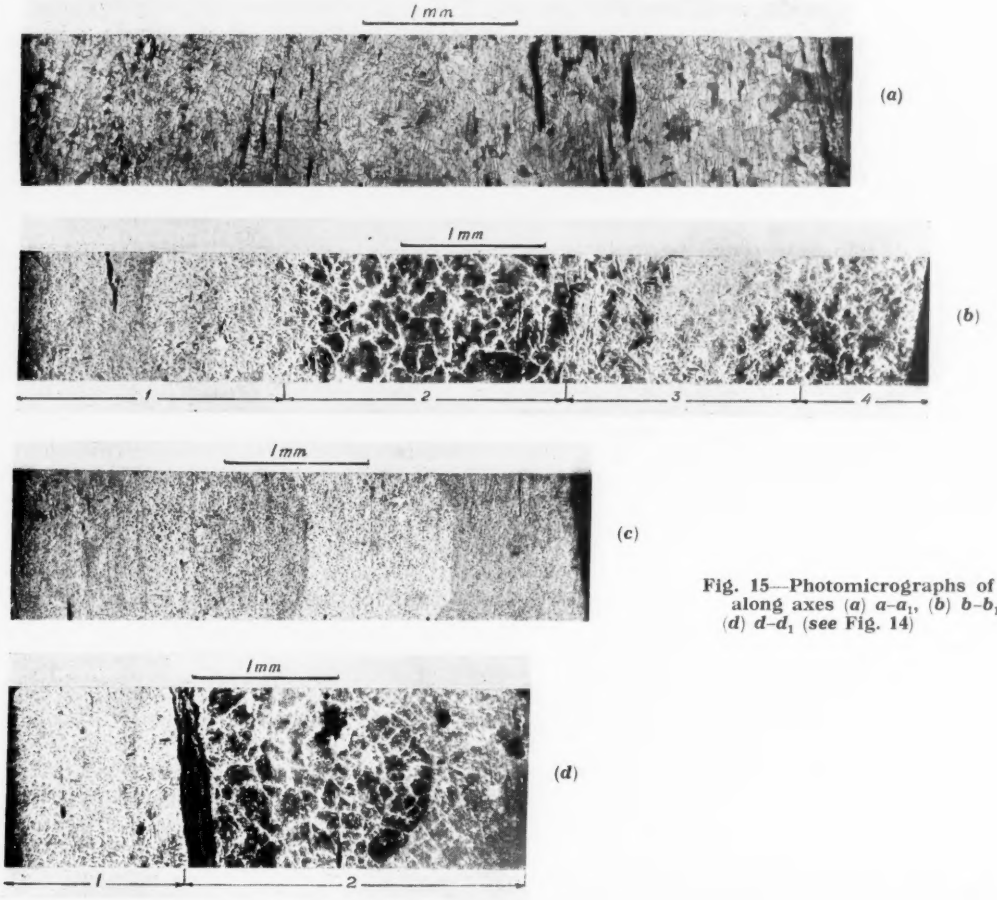


Fig. 15—Photomicrographs of clamp *E* along axes (*a*) a–a_1, (*b*) b–b_1, (*c*) c–c_1, (*d*) d–d_1 (*see* Fig. 14)

Table XI

SUMMARY OF HARDNESS AND U.T.S. RESULTS

	Hardness Δ, kg/mm²		U.T.S. S_u, kg/mm²	
	Max.	Min.	Max.	Min.
Dowel *L*	79	68	28·40	24·50
Dowel *N*	166	88	59·76	31·68
Clamp *B*				
Flange	140	85	50·40	30·60
Web	235	87·4	...	31·50
Clamp *E*				
Flange	130	91	46·80	32·76
Web	124	91	44·64	32·76

determined on all the available sections, owing to lack of sizes suitable for the preparation of specimens.

Clamp *B* alone has supplied two tensile specimens, taken from the web of the clamp, from which it has been possible to determine coefficients of mechanical properties (*see* Table VII).

Hardness Tests—The maximum and minimum values derived from the hardness tests are shown in Table XI, which also gives the approximate U.T.S. derived from the formula $S_u = 0{\cdot}36\ \Delta$.

Heterogeneity in Grain Size of Crystals—The material of the dowels and clamps examined displays a lack of uniformity in the grain size of crystals, which is very marked in certain of the sections examined. This is due in places to overheating, which gave rise to large crystals, and in others to local alterations in the grain size of crystals owing to hardening; such hardening was the result of cold hammering, giving rise to an increase or decrease in the size of the crystals in the material. These were finish hammerings in the manufacture of the various pieces when the metal was chilled. The results of the finish hammerings became evident on reheating the dowels and clamps before plunging them in the molten lead poured into the cavity. During reheating the material was in most cases not left long at the recrystallizing temperature; accordingly, such recrystallization was not completed, producing a mixture of coarse-grained and fine-grained ferrite at several points.

Carburization—The reheating of the dowels and clamps, effected in a charcoal fire and under a temperature of about 900° C, led to varying local carburization of the material. Where the reheating occurred in the presence of charcoal powder and CO, carburization was strong and pearlite was revealed; where this took place in the presence of CO alone, carburization was weak, with consequent sub-eutectic state and ferrite. In general, carburization is superficial, because the metal was not left for long in a carburizing temperature and surroundings.

Local Tempering—Laying the dowels and clamps into the fused lead in the cavity required adequate heating.

Local tempering is detected on the clamps at points where the cold tongs gripped the heated clamps and the metal could be tempered. This generally occurred on the flanges of the clamps, as found in the course of the research on clamps *B* and *E*. On clamp *W*170, examined by Campbell, the tongs held the clamp on the web at the neck. The author does not agree with Campbell's attribution of the mild hardening to the pressure on the metal by gripping in a vice while the base was upset. Such pressure is not necessary for refolding clamps of the *B* type and is in no way applicable in making the type *E* clamps.

No local tempering has been detected on the section of dowel *L* examined, as the iron did not carry sufficient carbon (mean content 0·163%) at the spot where the cold tongs gripped the heated dowel. Likewise, no local tempering has been noticed on the section of dowel *N* examined, although the carbon content of the iron (mean content 0·395%) rendered this possible at several points, as the tongs must have gripped the heated dowel at the missing part of the dowel which was not intended to be plunged into fused lead.

Fashioning of the Clamps—Two methods of making double-**T**-shaped clamps are evidenced: one by refolding and welding a metal strip and the other by welding three separate metal strips. As already stated, welding was known to the ancient Greeks as early as 560 B.C.

METALLURGY OF THE IRON OF THE PARTHENON

Hypotheses on Ancient Greek Ferrous Metallurgy

In order to express an opinion on the metallurgy of the iron of the Parthenon, it is necessary to set out briefly the hypotheses put forward by various research workers on ferrous metallurgy at the time of the ancient Greeks.

These are of a very general character and are in no way chronologically defined; they refer to the technique during eleven centuries—i.e. from Homer (1100 B.C.) to Plutarch (A.D. 46)—a period that covers three epochs, namely, the Heroic, the Classic, and the Hellenistic. These hypotheses are therefore not *a priori* strictly accurate in their application at the time the Parthenon was erected, because during these eleven centuries a substantial development was recorded in the metallurgy of iron.

Blumner, Rickard, and Harbord are three of the outstanding writers who have dealt with the subject. Of these, only Blumner bases his work (but only in part) on the relevant ancient Greek texts, and his views on the metallurgy of iron by the ancient Greeks are of a general character only. The other two writers express opinions based on the assumption that the methods of the ancient Greeks must have been primitive and that as such they should coincide with the methods used by primitive peoples of the present day. According to them, therefore, an investigation into the methods used by present primitive peoples can help in assessing the metallurgy of the ancient Greeks.

Blumner's Hypothesis—On the subject of the smelting of iron and the nature of the resultant material, Blumner reports the following (*op. cit.*,[1] vol. 4, pp. 211 *et seq.*):

> " The equipment of the ancients for smelting iron ore, in contrast to the modern blast-furnaces, had low hearths which did not permit the prolonged effect of the carbon gases on the iron ore. These hearths, in addition, owing to inefficient blowing equipment, could not develop high temperatures and thus were not in a position to produce cast iron. The ancients had to limit themselves to an incomplete removal of the iron

from the ore, which process requires a temperature lower than that needed for the production of cast iron. Owing to the inefficient blast in the primitive furnaces the iron was partly decarburized, after being reduced and while falling through the bath of oxidizing flux. Through an abundant use of wood and charcoal and with a suitable blast of air, it is possible to obtain a product consisting of a mixture of carbon-free iron and steel with phosphorus content, slag inclusions being removed by hot hammering. This product is sufficiently clean and strong but limited in output and furthermore is obtained with a most incomplete exploitation of the iron ore."

In pursuing his views on the smelting of iron by the ancient Greeks, Blumner makes the following further statement:

" The smelting of iron ore by the ancient Greeks was very incomplete and simple. A process, at present in use by the primitive peoples of Africa, was also applied by the ancient Greeks. At Kordofan in Africa the smelting of iron ore takes place at present in a primitive way as follows.

The iron ore, consisting of limonite, after washing is broken into pieces of bean size. Conical ditches, having a diameter of 30–35 cm. and a depth of about 35 cm., are dug out and filled with charcoal and the broken iron ore. Coal is then added and the whole mass is ignited. At the bottom of the ditch, at an angle of about 45°, the bellows tube is inserted and blowing begins. When the mass sets down owing to the smelting of the iron ore and the burning of the coal, new ore and new coal are added. After a lapse of 10 hr. the first part of the process is completed and the ditch is nearly filled with a thick semi-liquid mass. The bellows tube is withdrawn, the fire is extinguished, and the mass is left to cool down. In this way molten iron ores, which are kept for a second melting, are obtained. This is carried out in the same ditch with a stronger blow and lasts a few hours. Slags, very rich in iron content, float and are removed while in a liquid state. The remaining product on the bottom of the ditch is broken into pieces and, after being hammered with a view to removing the slag inclusions, is sold to the smiths as malleable iron."

Blumner further reports that the ancient Greeks must obviously have deviated from this process towards a more advanced method, by building hearths and more elaborate furnaces.

Harbord's Hypothesis—Dealing with the process of iron production used by the ancients, Harbord set forth the following opinion in the course of discussions held at The Iron and Steel Institute[10]:

" It is probable that the iron never collects in the fluid state on the bottom of the furnace, but as it is reduced and falls through the bath of oxidizing flux it is partly decarburized, its melting point raised and the temperature is just high enough to enable it to gather together in the form of a metallic sponge from which the fluid slag can be tapped off from time to time. This is true of all such primitive smeltings. The iron is not melted completely, it is never liquid, it is merely agglomerated into a sponge that is known to iron founders as a ' bloom ' which is a lump of crude iron called ' wrought iron ' because it has to be wrought or worked with the hammer before it is fit for implemental use."

Rickard's Hypothesis—Rickard states the following in regard to the matter under research[11]:

" Iron in sponge form such as was smelted by the ancients is what nowadays we term ' wrought iron.' It must be remembered however that the wrought iron produced by direct smelting from ore, as done by the primitive founder, is different from the wrought iron made today by the puddling process, in which pig iron is decarburized to the composition of the sponge iron of the ancients. So long as only wrought iron, that is to say, malleable iron, free from carbon was the objective of the smelting operation, it was impossible to obtain entire fusibility except at a temperature usually beyond the scope of the primitive furnace, for pure iron is not completely melted until a temperature of 1530° C. is attained. A sufficient addition, say 4%, of carbon will make a metal that can be cast into shape, that is, completely fused at 1130° C. Our ancient artificer did not want such iron, and if he made any inadvertently, as necessarily he must have done occasionally, he rejected it as a metallurgic abortion unfit for his purpose.

Most descriptions of iron smelting by backward peoples as witnessed by modern Europeans are incorrect in their details, because the observer rarely happens to be versed in metallurgy. However, from the variant accounts of travelers we can form a fairly good idea of such crude practices as must likewise have been in vogue among the more primitive peoples of the past."

Rickard gives descriptions of iron smelting by various peoples of Africa, as recorded by explorers; these may be summarized as follows. The iron ore is broken into small pieces and placed in primitive furnaces in layers, with alternate layers of coal. The blowing is operated from underneath and the iron ore yields the iron, which is collected from the bottom of the furnace and hot-hammered with a view to removing the slag.

Views of the Present Author

The author's views[12] on the metallurgy of the iron of the Parthenon are based on the findings of the experimental investigation conducted on the dowels and clamps of the Parthenon, and on the texts of ancient Greek writers who lived at about the time the Parthenon was erected (447–438 B.C.) and who make incidental statements about the metallurgy of iron. These writers are Aristotle (384 B.C.) and Theophrastus (372–287 B.C.).

There is a lapse of about a century between the time the Parthenon was built and the period in which their texts relating to ferrous metallurgy were written. This may be overlooked if it is realized that ferrous metallurgy, even during the Classic period, did not record any essential development from half-century to half-century, or any appreciable difference between one locality and another.

Furthermore, as the technique of the iron of the Parthenon—and, indeed, the technique of the whole monument—was the best of that period, the most skilful technicians having been employed for its erection, and as the period was one of the finest in the history of art, it may be said that the technique of that period was superior to that of the half-centuries immediately following. Thus, by accepting the statements made in the texts of Aristotle and Theophrastus there is no exaggeration in the technique of ferrous metallurgy applied at the time the Parthenon was erected.

Smelting of Iron Ores—The experimental research reveals that the structural iron of the Parthenon consists in part of carbon-free iron and in part of steel of a variable carbon content, with slag inclusions. These findings are representative of the imperfect iron products of that period. To express an opinion on ancient ferrous metallurgy, however, it is necessary to set out the relevant texts of Theophrastus and

Aristotle and comment on them from a technical point of view.

Aristotle was born in 384 B.C. (it is not known when he died). The descriptive writings of this great philosopher, referring to approximately 350 B.C., carry unquestionable authority and constitute the principal foundations on which the present opinions are based.

Aristotle investigated various technical matters, including the process of iron smelting. In *Meteorologica* the following passage occurs, referring to iron:

> " and the fireproof stone is smelted sufficiently to drop and flow; and on being solidified after flowing becomes again hard " (IV, 6, p. 383, B5).

Thus fireproof stones were added to the iron ore mixed with charcoal, for purposes of efficient slag removal, from which it may be concluded that the iron of that period was smelted in furnaces with a relatively efficient blowing system by means of leather-bag blowers, ensuring a sufficiently high temperature under which the ores and the refractory stones were fused together, thus producing a semi-fluid mixture capable of dropping and flowing.

' Dropping ' refers to the semi-fused mass of the metal ore that falls in drops to the bottom of the furnace. ' Flowing ' refers to the flow of the metal coming out of the furnace, which implies the existence of an inclined furrow near the base of the furnaces of that period, permitting the flow and drainage of the molten metal.

For purposes of iron-ore smelting, therefore, the furnaces of that period did not consist merely of ditches dug in the ground, as surmised by the researchers mentioned earlier. Such furnaces were probably built above ground level or suitably dug in the soil, to permit outflow of the metal from their bottom.

The description by Theophrastus on the subject is similar to that by Aristotle. Theophrastus was born in 372 B.C.; he was therefore a contemporary of Aristotle—his successor in the Peripatetic School and a member of the Platonic Circle. He is distinguished for his power of observation and his precision of expression in matters relating to the smelting of ores. In regard to the smelting of iron ore, he reports the following in his *History of Stones*:

> " . . . and upon firing, the stones are smelted and flow like the ores. And together with the silver, the copper, and the iron also flow the stones which derive from these, either on account of the fluidity of the silver, the copper, and the iron, or by themselves. And the fireproof stones and the millstones melt with the matter laid upon these by the miners."

This establishes the addition of stones (probably pyritic) to segregate the slag. The second sentence of the quotation confirms the flow, reported by Aristotle, of the fused iron ore which, after being chilled, appeared as a spongy mass, consisting in part of malleable iron and in part of steel of a variable carbon content, together with abundant slag. The third sentence, which is of great interest, reveals that the iron ore, together with the coal, was placed on the fireproof stones and mill-stones which thus served as a grille in the furnaces; under the effect of the fire, this stone grille was in time worn away and the material was carried away with the fused iron ore.

Iron and Steel Production Process—Aristotle supplies interesting information about the way in which the product of smelting is further cleaned of slag and converted into a steel-bearing iron capable of being tempered.

The following is an excerpt from *Meteorologica*:

> " And the wrought iron is melted so as to become liquid, and then solid again. And the hardening of iron into steel is made in the following way: the iron sinks to the bottom and the slag is removed by purging and when this is repeated over and over again and the iron is purified, the conversion of iron into temperable steel has occurred. And this operation is not repeated many times because there is a great loss, and the degree of purification is less. Besides, the best iron is that which is less pure " (IV, 6, p. 383, A29).

The term ' wrought ' implies that the product of smelting has been worked; such work is believed to have consisted of hot hammering to remove the slag inclusions. For this purpose, the product of smelting was broken into pieces of suitable size for hammering. The slag removal by hammering, although not complete, was expedient as it did not cause any loss of useful metal.

These pieces of wrought iron were subsequently fused together according to the method described by Aristotle. Such co-fusion must have taken place in a pot, the technical purpose of which has not yet been established; this pot was called *periodos* (Blumner, *op. cit.*,[1] vol. 4, p. 208). Its use is reported by Polydeutis as follows:

> " . . . and the pot into which they mix the iron is called *periodos* in books referring to metals, whether the book is of Aristotle or of Theophrastus " (VII, 99).

Inability on the part of the blacksmith of that period to achieve sufficiently high temperatures resulted in a non-flowing fusion of the mixture within the *periodos*; this led to the existence within the melting-pot of a semi-fluid and heterogeneous mass of metal, consisting of three layers. Carbon-free iron, which is more difficult to melt than carburized iron, was in a thick-flowing condition and sank to the bottom of the melting pot, thus constituting the lowest layer. Slag, being more fusible, remained in a fluid state and floated, thus constituting the uppermost layer. The middle layer consisted of steel, which is more eutectic than iron but more difficult to melt than slag. The floating slag was thrown away and the product of smelting was still further purified by the supplemental process described.

Repetition of this treatment, according to Aristotle, refined the metal and gave a temperable iron product. The ancient technician was particularly interested in this product, which is steel; accordingly, the metal was purged by removing the floating slag sparingly and carefully, in order to obviate simultaneous removal of the contiguous middle layer of steel, which would have wasted useful metal and produced a non-temperable commodity.

These considerations explain the last sentence of Aristotle's text—" . . . the best iron is that which is less pure." Iron that was less pure had a greater steel content, and was therefore temperable. It was thus favoured by the ancient blacksmith.

This treatment produced a commodity which was

a mixture of iron, steel of a variable carbon content, and slag. This product was only temperable so long as it carried adequate steel of the necessary carbon content. Pure iron could be produced if the refining of the contents of the pot was continued by removing the middle layer as well.

Fuel Used—The fuel used both in the metallurgy of iron and in its working at the time the Parthenon was erected was probably charcoal.

Theophrastus distinguishes various kinds of charcoal according to their wood or igin: pine, oak, fir, and Eubœan walnut.[t] For each variety of metalwork, the appropriate charcoal was used.[u] This is an indication of advanced technique in metalworking.

Theophrastus further refers to coal, which he calls 'mined coal.'[v] Its use was, however, apparently restricted.

Operation of an Ancient Furnace

In connection with the process of iron and steel production described in the previous section, it is of interest to note the existence at the British Museum of a *lekythos*, the design of which exhibits iron working of a hitherto unknown nature. This design (Fig. 16) reproduces a furnace of approximately the same diameter in both the upper and lower parts and of a height that cannot be accurately determined from the design. At the upper opening it carries a receptacle with a cover. At the base there is a hearth and in front an anvil. Behind the furnace and near the base is provided a blower consisting of a leather bag. Various tools are hung on the walls. On the right, a naked blacksmith is standing, holding a hammer. On the left, there is another technician, in a sitting posture; his left hand is held before his eyes for protection against the reflection of the fire; in his right hand he holds tongs with which he grips a piece of iron, suitably heated for hammering on the anvil.

Gerhard believes that this pottery design merely represents a melting pot. De Lannay (*see* Daremberg and Saglio, *op. cit.*,[3] p. 1082) holds the same view. Beck expresses the opinion that this pottery design shows a furnace in which the receptacle with a covering constitutes a device to close its opening.[13] But none of these authors can explain how it is possible to have hammering carried out in the vicinity of a melting furnace.

The present author, as a result of previous research,[12] believes that the pottery design represents a furnace for refining further the product of smelting, in accordance with the reported process of iron and steel

Fig. 16—Ancient Greek *lekythos*, with a design depicting metal-working processes. (*Reproduced by permission of the Trustees of the British Museum*)

production. Pieces of iron, constituting the smelting output, were heated for the purpose of hammering with a view to slag removal by means of the fire in the hearth at the base of the furnace, and the same fire heated the covered melting pot placed on top of the furnace, which is believed to be the *periodos*, for co-fusion of the wrought-iron pieces within. Thus, the man on the left grips a piece of unwrought iron removed from the fire of the hearth and ready for hammering to remove slag inclusions. Subsequently, after hammering on the spot, such iron, while still hot, was thrown into the *periodos*, in which it was fused along with other pieces, the remaining slag being removed when floating.

This furnace was used solely for the production of steel-bearing iron in the aforesaid manner. In support of this view, in other pottery designs (*see* Blumner, *op. cit.*,[1] vol. 4, pp. 365, 368) reproducing work connected with making iron products, there is no furnace of this nature, but there is a very different type, namely, an open low furnace, without an overlying pot, the purpose of which was to heat pieces of iron before making them into various objects by hammering.

Acknowledgments

The writer wishes to express his gratitude to the late Dr. Alexander Vournazos, Academician, Per-

[t] *History of Stones*, V, 9, 2: "And other charcoal is used for other purposes; for certain kinds of works, as at the blacksmiths', they seek soft charcoal produced from Eubœan walnut; at the silver workshops the demand is for charcoal produced from fir wood."

[u] *Op. cit.*, V, 9, 3: "And the blacksmiths prefer charcoal made from pine wood to that from oak wood, although the former is weaker; but it is better from the point of view of blowing, as it lasts longer, and its flame is stronger."

[v] *Op. cit.*, 16: "Those fossil substances that are called coals and are broken for use, are earthy; they kindle however and burn like charcoals. These are found in Liguria, where there is also amber, and in Elis, in the way to Olympias, over the mountains. These are used by the smiths."

manent Professor at the Athens Technical University, who supervised the present research and guided the writer. He also wishes to express his deep appreciation to Dr. Fr. Theodorides, former Professor at the Athens Technical University, who followed the progress of the research, extending valuable advice and assistance; to Mr. Apostolos Koutsocostas, Permanent Professor at the Athens Technical University, for valuable advice; to Mr. Stavros Hors, Permanent Professor at the Athens Technical University, and Director of the Analytical Chemistry Laboratory, and to his assistant, Mr. S. Vrachnos, who carried out the chemical analyses; to Mr. J. Miliades, Director of the Acropolis Museum; and to Professor Gorham Stevens, Honorary Architect of the American School of Archaeology in Athens, for his most valuable guidance and help.

Finally, the writer wishes to place on record his deep gratitude to Mr. L. C. Kemp, Managing Director of the Athens Piraeus Electricity Company, to whose kind initiative and action the translation of this text into English is due.

Bibliography and References

1. H. BLUMNER: "Technologie und Terminologie der Gewerbe und Künste bei Griechen und Römern": 1875–1887, Leipzig, B. G. Teubner.
2. H. C. RICHARDSON: *American Journal of Archaeology*, 1934, vol. 38, pp. 555–583.
3. C. DAREMBERG and E. SAGLIO: "Dictionnaire des Antiquités Grecques et Romaines": 1877–1919, Paris, Hachette et Cie.
4. A. R. RANGAVIS: "Antiquités Helléniques": 1842, Athens.
5. A. R. RANGAVIS: "History of Ancient Art": 1865, Athens, D. Koromylas.
6. P. CLOCHÉ: "La vie publique et privée des anciens Grecs," vol. 5—"Les classes, les métiers, le trafic": 1931, Paris.
7. F. C. PENROSE: "The Principles of Athenian Architecture": 1851, London, Society of Dilettanti.
8. M. MARIOLOPOULOS: *Minutes of the Academy of Athens*, 1937, vol. 5, p. 145.
9. W. CAMPBELL and E. E. THUM: *Metal Progress*, 1931, vol. 20, Nov., pp. 43–49, 94.
10. F. W. HARBORD: *J. Iron Steel Inst.*, 1904, No. II, p. 121.
11. T. A. RICKARD: *American Journal of Archaeology*, 1939, vol. 43, pp. 85–101.
12. A. VOURNAZOS: *Minutes of the Academy of Athens*, 1950, vol. 18, p. 338.
13. L. BECK: "Die Geschichte des Eisens in Technischer und Kulturschichtlicher Beziehung": 1884–1903, Braunschweig, Fr. Viewag und Sohn.
14. W. J. ANDERSON, R. P. SPIERS, and W. B. DINSMOOR: "The Architecture of Ancient Greece": 1927, London, B. T. Batsford Ltd.
15. A. L. MILLIN DE GRANDMAISON: "Minéralogie Homérique": 1790, Paris and Strasbourg.
16. N. BALANOS: "Les Monuments de l'Acropole. Relèvement et Conservation": 1938, Paris.

Interaction of Solutes in Liquid and Solid Solution in Iron

By E. T. Turkdogan

SYNOPSIS

Interactions of solutes in liquid and solid solution in iron are discussed. A simple measure of interaction is found to be the ratio of the activity coefficient of solute *Y* in a ternary solution, iron–*X*–*Y*, to that in the parent binary solution, iron–*Y*, at the same activity of *Y*. This ratio, designated Q_Y^X, is a continuous function of the concentration of the solute *X*, at a given temperature, but independent of the activity of the solute *Y*. Previous work on the Fe–Si–P–C and Fe–Si–Al–C–P–Mn–S systems show that a close agreement between the calculated and observed values of γ_C and γ_S can be obtained only in dilute solutions. 1172

Introduction

DURING RECENT YEARS there has been much study of the interactions between elements dissolved in solid and liquid iron. In almost all the iron-based binary and ternary systems investigated, marked positive or negative deviations from the laws of Raoult and Henry have been observed (*see* the critical survey of the thermodynamics of liquid metallic solutions by Chipman).[1] It is of importance to extend present knowledge of the thermodynamics of solutions to multi-component systems of wide composition range, and also to consider whether there is not some common pattern in the interactions of solutes.

By means of a Taylor series expansion for the logarithm of the activity coefficient, and omitting the terms involving second and higher derivatives, Wagner[2] obtained the following expression for very dilute solutions:

$$\gamma_2 = \gamma_2^2 \cdot \gamma_2^3 \cdot \gamma_2^4 \cdots \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where γ_2 is the activity coefficient of the solute 2 in a multi-component system 1–2–3–4 . . . , γ_2^2 is the activity coefficient in the binary 1–2 system, γ_2^3 and γ_2^4 are the activity coefficient factors in the ternary 1–2–3 and 1–2–4 systems. The above equation was originally suggested, on experimental evidence, by Sherman, Elvander, and Chipman[3] and Chipman and Elliott,[4] who showed that $\gamma_S^C (= \gamma_S/\gamma_S^S)$ was a function of carbon concentration but independent of sulphur content of the metal.

Equation (1) is valid only for very dilute solutions, and as shown by Sherman and Chipman,[5] in Fe–Si–Al–C–P–Mn–S multi-component systems, such as may

Paper C/2/55 of the Chemistry Department of the British Iron and Steel Research Association, received 15th June, 1955.

Dr. Turkdogan is Head of the Physical Chemistry Section of the Chemistry Department of B.I.S.R.A.

arise in practice, an empirical method has to be used to calculate the activity coefficient of sulphur. However, the results obtained by Smith[6] on the activity of carbon in Fe–Si–C and Fe–Mn–C ternary alloys at 1000° C indicate that for a given silicon or manganese concentration, γ_C^{Si} or γ_C^{Mn} increases with increasing carbon concentration. In the case of Fe–Cr–C melts, investigated by Richardson and Dennis,[7] γ_C^{Cr} increases, for a given chromium concentration and temperature, as the carbon content of the metal is lowered.

The few examples above indicate that the activity *v.* composition relationships in dilute ternary and multi-component systems do not conform to a simple general rule.

The purpose of this paper is to discuss interactions in iron-based solutions, which have been investigated recently by various workers, with a view to discovering a formula or a rule which will apply to all solutions over a wide composition range.

Fe–Si–C SYSTEM

Activity Coefficient of Carbon

An attempt has been made by the author[8] to compute the activity coefficient of carbon dissolved in Fe–Si–C melts. It was shown, from the data of Smith[6] on Fe–Si–C alloys at 1000° C, that ΔN_C^{Si} was a continuous function of the silicon concentration, where ΔN_C^{Si} is the amount of carbon displaced by added silicon at a given carbon activity, i.e.

$$\Delta N_C^{Si} = N_C - N_C^C \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where N_C and N_C^C are the atom fractions of carbon in Fe–Si–C and Fe–C systems, respectively. For a given silicon content, the amount of carbon displaced by the dissolved silicon increased with carbon activity of the solution. In other words, ΔN_C^{Si} was a function of the two independent variables, silicon concentration and carbon activity. To eliminate one of the variables, the ratio $\Delta N_C^{Si}/N_C^C$ was plotted against the atom fraction of silicon; the relationship was found to be independent of the carbon activity.

From the known solubilities of graphite in Fe–Si melts,[9] it was possible to show that ΔN_C^{Si} was a continuous function of N_{Si} at unit carbon activity at any

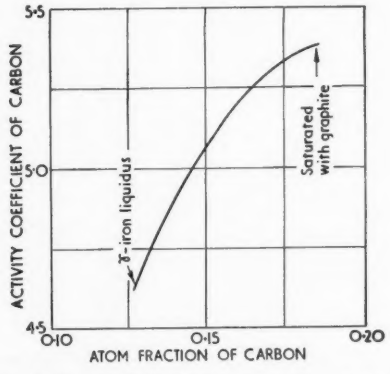


Fig. 1—Activity coefficient of carbon dissolved in iron at 1300° C; β-graphite is the standard state

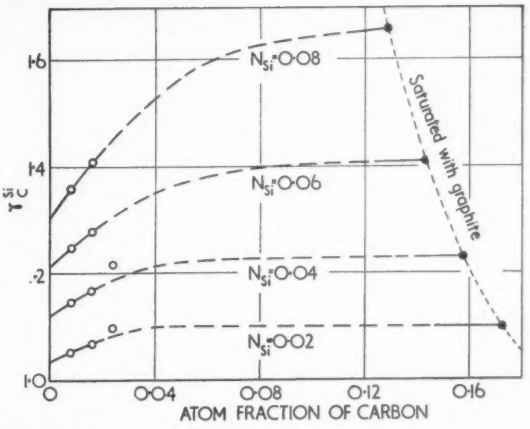


Fig. 2—Activity coefficient factor γ_C^S related to Si and C concentrations for melts at 1300° C. Symbol γ_C^{Si} will later be substituted by P_C^{Si}

temperature.[10] On the assumption that these relationships were also valid at lower carbon activities, it became possible to calculate the activity coefficient of carbon in Fe–Si–C melts at any temperature. From the computed results, the activity coefficient factor

$$\gamma_C^{Si} = \frac{\gamma_C}{\gamma_C^C} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

was related to composition, γ_C and γ_C^C being the activity coefficients of carbon in the ternary and binary solutions at the same carbon concentration. The value of γ_C^{Si} depended strongly on silicon concentration and to a small extent on the carbon concentration.

Some experiments are being carried out in these laboratories to determine the thermodynamic properties of Fe–C melts at various temperatures and concentrations and it is now possible to show the variation of carbon activity at 1300° C within the composition range extending from the γ-iron liquidus curve to the limit of solubility of graphite. Figure 1 illustrates this relationship, β-graphite being the standard state.

By means of the data on the solubility of graphite in Fe–Si melts[9] together with Fig. 1, it is possible to calculate the value of γ_C^{Si} at 1300° C at unit carbon activity. The results are given in the following table:

N_{Si}	N_C	γ_C	γ_C^C	γ_C^{Si}
0·08	0·1290	7·751	4·670	1·66
0·06	0·1432	6·983	4·955	1·41
0·04	0·1574	6·353	5·170	1·23
0·02	0·1718	5·821	5·310	1·10

In Fig. 2, γ_C^{Si} is plotted against the atom fraction of carbon at various silicon concentration levels. The points on the low-carbon side are calculated[8] and those at carbon saturation are the experimental results taken from the above table. Although there is still a wide gap between the points in Fig. 1 over the medium- and high-carbon concentrations, the effect of carbon on γ_C^{Si} becomes more marked as silicon concentration increases. Furthermore, it is clear that only in solutions dilute with respect to silicon, e.g. $N_{Si} < 0{\cdot}01$, is it permissible to use equation (1).

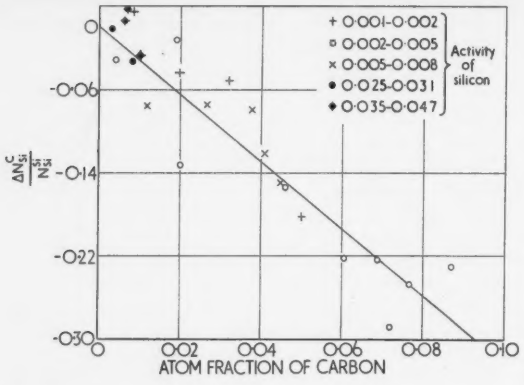


Fig. 3—Relationship between $\Delta N_{Si}^{C}/N_{Si}^{Si}$ and the concentration of carbon for melts at 1420° C

Activity Coefficient of Silicon

Chipman *et al.*[11] have recently made an extensive study of the thermodynamics of silicon dissolved in Fe–C melts. One of the conclusions they reached was that γ_{Si}^{C}, i.e. $\gamma_{Si}/\gamma_{Si}^{Si}$ where γ_{Si} and γ_{Si}^{Si} are the activity coefficients of silicon in the ternary and binary solutions, was independent of the silicon content of the melt. A closer examination of their plot of log γ_{Si}^{C} against carbon concentration indicates that a series of lines could be drawn so that for a given carbon content, log γ_{Si}^{C} increases with silicon concentration. However, an attempt will now be made to calculate γ_{Si}^{C} from their data in such a way that a much wider composition range may be covered without the need for additional experimental work.

As in the case of carbon discussed above, the following expression may be written:

$$\Delta N_{Si}^{C} = N_{Si} - N_{Si}^{Si} \quad \ldots\ldots(4)$$

where N_{Si} and N_{Si}^{Si} are the atom fractions of silicon in the ternary and binary solutions at the same silicon activity. From the results of Chipman and coworkers,[11] the values of $\Delta N_{Si}/N_{Si}^{Si}$ have been calculated and plotted against the atom fraction of carbon for five ranges of silicon activities. It is clear from Fig. 3 that the points are scattered at random about the line drawn and that there is no tendency for the activity of silicon to influence this relationship, which may be represented by the following linear expression:

$$\frac{\Delta N_{Si}^{C}}{N_{Si}^{Si}} = -3{\cdot}23N_{C} \quad \ldots\ldots(5)$$

at 1420° C and up to 0·1 atom fraction of carbon.

Combining equation (5) with the activity *v.* composition relationship in Fe–Si binary melts at 1420° C,[11] the values of γ_{Si} and γ_{Si}^{C} can be calculated in a way of which the following is an example. Assume an Fe–Si melt with N_{Si}^{Si} of 0·15 and by means of equation (5) find the value of ΔN_{Si}^{C} for a ternary alloy with $N_C = 0{\cdot}04$ at 1420° C; it is $-0{\cdot}0194$, and therefore by equation (4), $N_{Si} = 0{\cdot}15 - 0{\cdot}0194 = 0{\cdot}1306$. The activity of silicon at $N_{Si}^{Si} = 0{\cdot}15$ is 0·00080 according to the above workers' results. Since equation (5) holds only when the silicon activity of both binary and ternary melts at these compositions and temperatures are the same, it then follows that

$$\gamma_{Si} = \frac{0{\cdot}00080}{0{\cdot}1306} = 0{\cdot}0061.$$

In Fig. 4, γ_{Si}^{C}, i.e. $\gamma_{Si}/\gamma_{Si}^{Si}$ at the same silicon concentration, is plotted against the atom fraction of carbon for a series of silicon concentrations up to the limit of graphite solubility and the formation of SiC (point *Z*). It is clear that the factor γ_{Si}^{C} is a function of the carbon as well as the silicon content of the metal.

In the above calculations the standard states for carbon and silicon were β-graphite and pure molten silicon. However, since the factors γ_{C}^{Si} and γ_{Si}^{C} are the ratios of the activity coefficients at given concentrations of carbon and silicon respectively, these factors are not affected by the choice of the standard states, so long as they are the same for the binary and ternary systems.

In their paper, Chipman *et al.*[11] postulated that the atom fractions of carbon and silicon were equivalent in their effects on the activity coefficient of silicon. It is now possible to show to what extent this postulate applies. From equation (5) and silicon activity *v.* concentration relationship in the binary system, the following values may be obtained for the solutions at 1420° C:

$a_{Si} \times 10^4$	N_{Si}^{Si}	$-\Delta N_{S.}^{C}/N_{C}$
8·0	0·15	0·48
16·2	0·20	0·65
37·8	0·25	0·81
120·2	0·31	1·00
284·5	0·35	1·13

If carbon and silicon were equivalent in their effects on the activity of silicon, the term $-\Delta N_{Si}^{C}/N_{C}$ would be 1·0. The silicon activity in the above workers' experiments varied from 11×10^{-4} to 382×10^{-4},

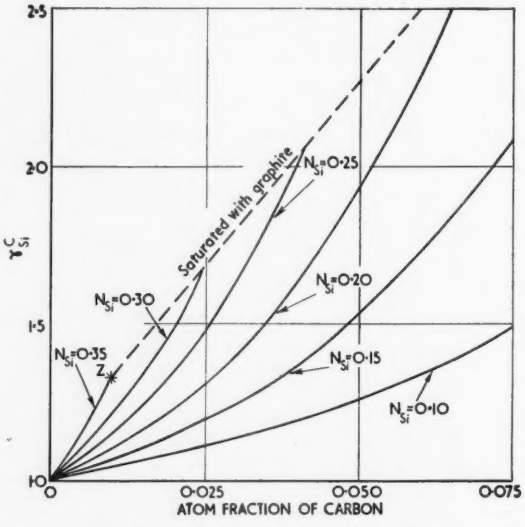


Fig. 4—Activity coefficient factor γ_{Si}^{C} related to C and Si concentrations for melts at 1420° C. Symbol γ_{Si}^{C} will later be substituted by P_{Si}^{C}

and as indicated by the values above, their equivalence postulate is approximately valid only when the silicon activity is between 40×10^{-4} and 280×10^{-4}.

Fe–Cr–C SYSTEM

Activity Coefficient of Carbon

When the usefulness of the ratio $\Delta N_C^X/N_C^C$ (X is the third dissolved element) was first discussed,[8] it was suggested that there was not a simple relationship between $\Delta N_C^{Cr}/N_C^C$ and N_{Cr} in Fe–Cr–C melts. A closer examination of the data on this ternary system indicates that this suggestion was incorrect.

Richardson and Dennis[7] have investigated the effect of chromium on the thermodynamic activity of carbon in liquid iron by equilibrating melts with $CO–CO_2$ mixtures of known composition at 1560°, 1660°, and 1760° C, over a wide range of chromium and carbon concentrations. From these data the values $\Delta N_C^{Cr}/N_C^C$ have been calculated and plotted in Fig. 5 against the carbon activity, represented in terms of $(p_{CO})^2/p_{CO_2}$ in atmospheres, for a given temperature and chromium concentration. For the sake of clarity, only some of the results are included in Fig. 5, which clearly indicates that the ratio $\Delta N_C^{Cr}/N_C^C$ is independent of the carbon activity for a given temperature and chromium content. The following summarizes the values of N_{Cr} and $\Delta N_C^{Cr}/N_C^C$ within the range covered by the experiments:

Temp., ° C	N_{Cr}	$\Delta N_C^{Cr}/N_C^C$
1560	0·0985	0·48
1560	0·2434	1·57
1560	0·4323	4·42
1660	0·0980	0·49
1660	0·2430	1·68
1660	0·4569	4·01
1760	0·0948	0·59
1760	0·2389	1·82
1760	0·4606	3·92
1760	0·7059	12·80

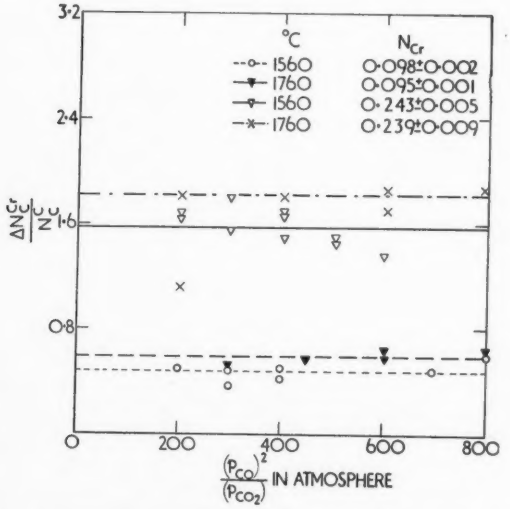


Fig. 5—The ratio $\Delta N_C^{Cr}/N_C^C$ related to the activity of carbon at a given temperature and chromium concentration

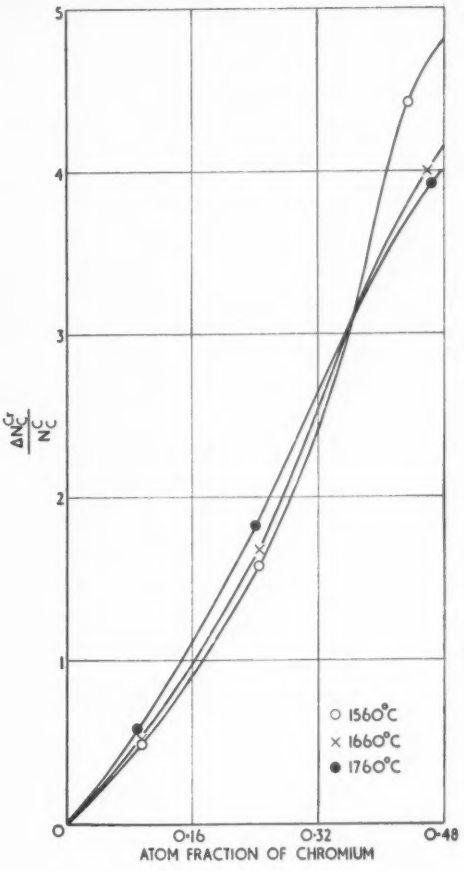


Fig. 6—Relationship between $\Delta N_C^{Cr}/N_C^C$ and the concentration of chromium for melts at 1560°, 1660°, and 1760° C

In Fig. 6, the values of $\Delta N_C^{Cr}/N_C^C$ are plotted against the atom fraction of chromium at three temperatures. When the value of N_{Cr} is greater than 0·36 the effect of temperature is the reverse of that observed at lower chromium concentrations. Figures 5 and 6 show that the Fe–Cr–C system can be treated in the same way as the other systems mentioned above and that it is possible to compute γ_C by the method described. The results of such calculations are not given here as Richardson and Dennis have shown very clearly the effects of temperature and composition on the activity coefficient of carbon by a series of diagrams. Note also that the factor γ_C^{Cr}, for a given chromium content and temperature, decreases as the proportion of carbon increases.[12]

Fe–*X*–S SYSTEMS

Activity Coefficient of Sulphur

The interactions of a number of elements with sulphur dissolved in iron have been investigated by various workers.[3, 5, 13, 14] Their results have been

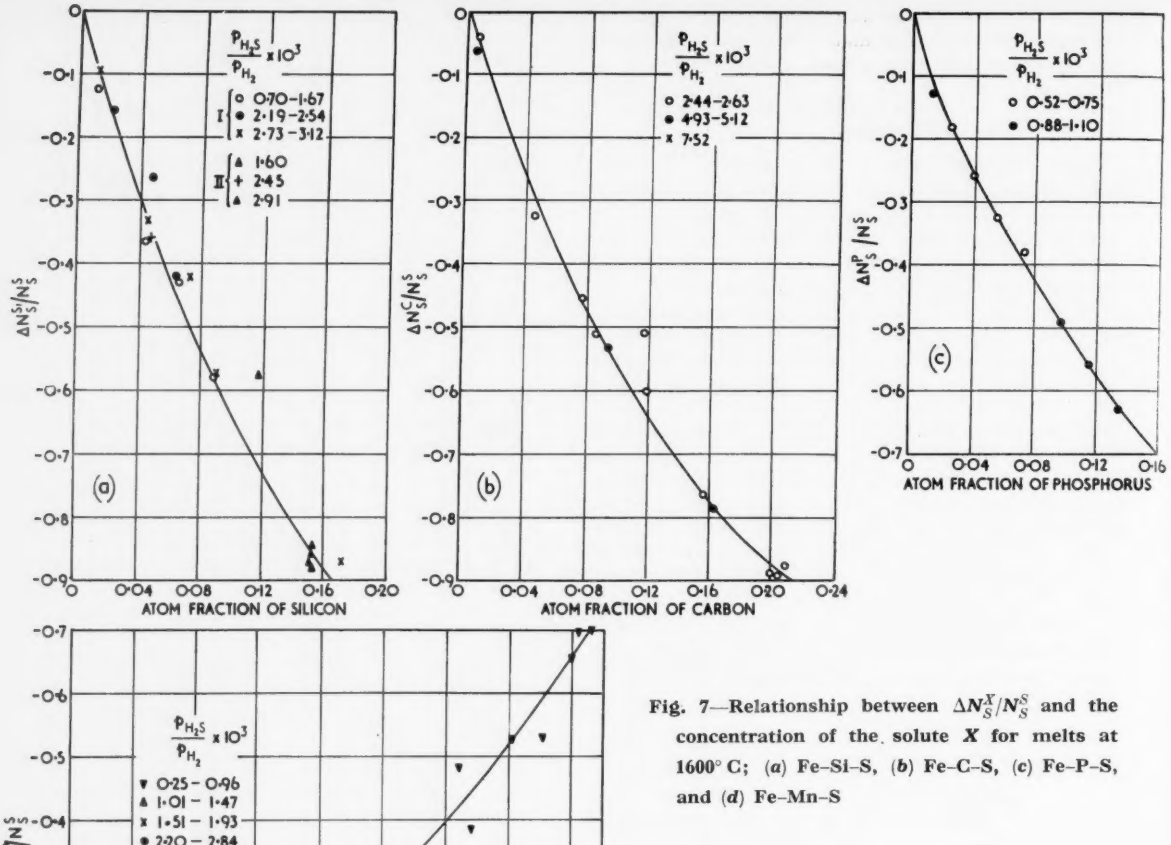


Fig. 7—Relationship between $\Delta N_S^X/N_S^S$ and the concentration of the solute X for melts at 1600° C; (*a*) Fe–Si–S, (*b*) Fe–C–S, (*c*) Fe–P–S, and (*d*) Fe–Mn–S

used to calculate the ratio $\Delta N_S^X/N_S^S$, where X represents Si, C, P, or Mn, for ranges of sulphur activities at 1600° C. In Figs. 7*a–d* the values of $\Delta N_S^X/N_S^S$ are plotted against the atom fractions of X.

In Fig. 7*a*, the experimental results of Morris and Williams (I)[14] at 1615° C and of Sherman and Chipman (II)[5] at 1630° C have been corrected to 1600° C, so that they could be directly compared with the curves in Figs. 7*b–d*; this correction has been made in the following way. It was shown by Turkdogan and Leake[10] that the amount of carbon displaced by any alloying element added to carbon-saturated iron was a continuous function of the concentration of the added element, Si, P, but independent of temperature; further work[15] indicated that the same phenomenon applied also to Fe–S–C melts at saturation with respect to graphite. It may therefore be assumed that, in the case of the Fe–Si–S ternary system, the term ΔN_S^{Si}, at a given sulphur activity, is independent of temperature (at least within a narrow range of 1600° C); that is, the values of ΔN_S^{Si} obtained for 1615° and 1630° C are assumed to be valid for 1600° C, and the values used in Fig. 7*a* have been obtained by dividing ΔN_S^{Si} by N_S^S for the same sulphur activity at 1600° C.

It is clearly indicated by the curves in Fig. 7 that the ratio $\Delta N_S^X/N_S^S$ is a function of the concentration of X and independent of the sulphur activity of the system. The curves in Fig. 7 may be used to compute the activity coefficient factor γ_S^X, at various concentrations of X and sulphur; to do this, however, it is necessary to know the relationship between p_{H_2S}/p_{H_2} and the sulphur content of pure iron. The following, which is based on the results of Sherman *et al.*,[3] provides the required information:

Fe–S System at 1600° C

$p_{H_2S}/p_{H_2} \times 10^3$	a_S	N
2·812	0·01847	0·02
5·187	0·03411	0·04
7·197	0·04732	0·06
8·845	0·05817	0·08
10·210	0·06714	0·10

The variation of the sulphur activity coefficient with composition is given by the following expression for the temperature range 1500–1700° C and up to 0·1 N_S^S (about 4·5% sulphur):

$$\log \gamma_S^S = -1{\cdot}73\, N_S^S \quad \ldots\ldots(6)$$

The value of γ_S in Fe–X–S ternary melts have been derived from the curves in Fig. 7 and equation (6) in the way described for the Fe–Si–C system. For the sake of brevity, γ_S *v.* composition diagrams have not been reproduced in this paper. However, for a given concentration of silicon, carbon, or phosphorus, the value of γ_S^X decreases with increasing sulphur content of the metal. In the case of Fe–Mn–S melts, however, γ_S^{Mn} increases with increasing sulphur content at a given manganese concentration.

DISCUSSION

Let us consider an iron-based liquid ternary system Fe–X–Y. From the thermodynamic data on the systems Fe–X–Y and the parent binary system Fe–Y, it is possible to find the effect of the solute X on the activity coefficient of Y; this factor has been designated by γ_Y^X and defined as

$$\gamma_Y^X = \frac{\text{activity of } Y \text{ in Fe–}X\text{–}Y}{\text{activity of } Y \text{ in Fe–}Y} \quad \ldots\ldots(7)$$

at a given atom fraction of Y. The factor γ_Y^X varies with the concentrations of the solutes X and Y as shown by the experimental results on Fe–Si–C and Fe–Mn–C alloys[6] at 1000° C, and Fe–Cr–C melts[7] at 1560°, 1660°, and 1760° C. Since, in general, the variation of γ_Y^X with the concentration of Y is not so great as that with the concentration of the solute X, it is often assumed that γ_Y^X is independent of the Y content of the system, e.g. in ternary systems containing sulphur.[3, 5, 13, 14] To produce a more complete picture of the γ_Y^X *v.* composition relationship, it would be necessary to carry out a much larger number of experiments to cover a given composition range.

In the foregoing sections of this paper it has been shown that the ratio $\Delta N_Y^X/N_Y^Y$ is a most useful term in the interpretation of the experimental results on the study of interactions in iron-based ternary systems. The significance of this ratio will now be considered. When a third element X is dissolved in an Fe–Y binary system, at a given activity of Y, in general, either more Y must be dissolved in the solution, or some must be displaced so that the activity of Y remains unaltered. This may be represented by the following expression:

$$\Delta N_Y^X = N_Y - \Delta N_Y^Y \text{ (at a given activity of } Y) \quad \ldots(8)$$

where N_Y and N_Y^Y are the atom fractions of Y in the ternary and binary systems, respectively. As already pointed out, ΔN_Y^X was found to be independent of temperature in carbon-saturated Fe–Si, Fe–P, Fe–S .[10, 15] Furthermore, as indicated by the curves in Figs. 3, 5, and 7 and in a previous paper,[8] the ratio $\Delta N_X^Y/N_Y^Y$ is independent of the activity of Y in the systems Fe–Si–C at 1000° C, Fe–C–Si at 1420° C, Fe–Cr–C at 1560°, 1660°, and 1760° C, Fe–Si–S, Fe–C–S, Fe–P–S, and Fe–Mn–S at 1600° C.

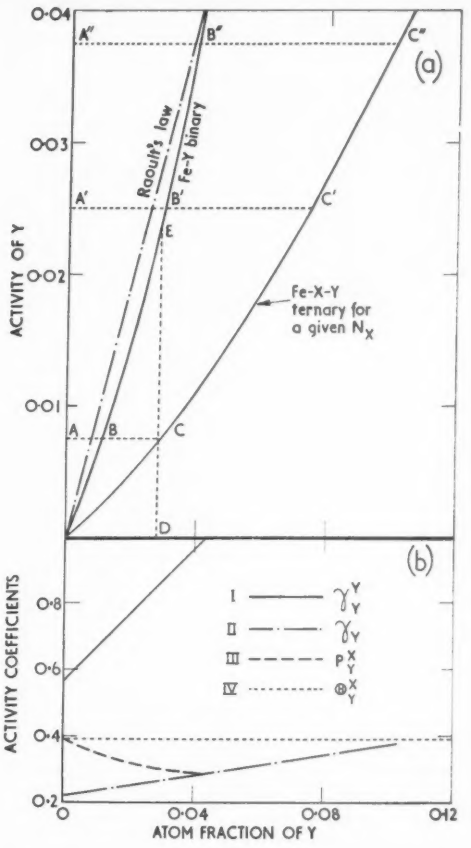


Fig. 8—Activity and activity coefficients of Y in Fe–Y and Fe–X–Y systems at a given temperature and concentration of the solute X

From equation (8) it follows that

$$\frac{\Delta N_Y^X}{N_Y^Y} = \frac{N_Y}{N_Y^Y} - 1 \quad \ldots\ldots(9)$$

Since the activity of Y is kept constant, this expression takes the following form when concentrations are replaced by the activity coefficient terms:

$$\frac{\Delta N_Y^X}{N_Y^Y} + 1 = \frac{\gamma_Y^Y}{\gamma_Y} \quad \ldots\ldots(10)$$

For convenience, the reciprocal of the right-hand side of equation (10) will be symbolized by Q_Y^X. There are therefore two ways of representing the effect of the solute X on the activity coefficient of Y, thus:

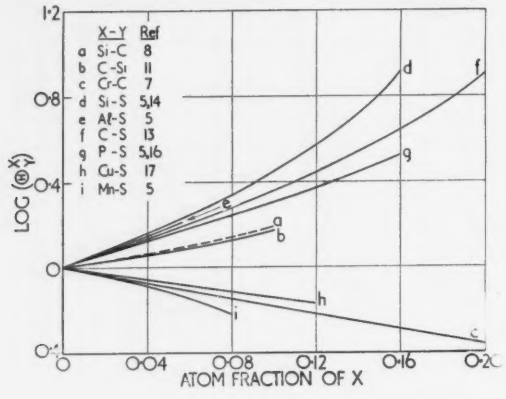


Fig. 9—Log Q_Y^X related to the atom fraction of the solute X for various ternary systems; the curves *a* and *b* are for melts at 1300° and 1420° C and the others for 1600° C

(i) At a given temperature and activity of Y:

$$Q_Y^X = \frac{\gamma_Y}{\gamma_Y^Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

(ii) At a given temperature and concentration of Y:

$$P_Y^X = \frac{\gamma_Y}{\gamma_Y^Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

It should be noted that γ_Y^X used previously is now replaced by P_Y^X. The difference between Q_Y^X and P_Y^X is that, at a given temperature, the former is a function of the concentration of X only, whilst the latter varies with the concentrations of X and Y. This concept may best be illustrated schematically by Figs. 8*a* and 8*b*, where the activity and the activity coefficient of Y, are plotted against atom fraction in an Fe–X–Y solution containing a fixed proportion of the solute X. The value of Q_Y^X is given by

$$Q_Y^X = \frac{AB}{AC} = \frac{A'B'}{A'C'} = \frac{A''B''}{A''C''} \quad \ldots\ldots\ldots (13)$$

and is constant at a given temperature and concentration of the solute X, as indicated by the dotted line in Fig. 8*b*. On the other hand, the ratio $P_Y^X = DC/DE$ varies with the concentration of Y; in this particular case, P_Y^X decreases as N_Y increases. Note that $Q_Y^X = P_Y^X$ as $N_Y \to 0$. A simple geometrical consideration will also indicate that when Henry's law is obeyed, Q_Y^X is equal to P_Y^X and therefore the latter also becomes independent of the concentration of Y, e.g. in iron-based ternary melts containing oxygen.

In Fig. 9, $\log Q_Y^X$ is plotted against the atom fraction of the solute X for all the ternary systems which have been investigated. For convenience, in Table I the values of $\log Q_Y^X$ are given for various concentration of N_X.

The only exception so far observed to the simple relationship between Q_Y^X and N_X is that in the Fe–Mn–C alloys at 1000° C. Calculations based on the data given by Smith[6] indicate that for a given manganese concentration the value of Q_C^{Mn} decreases slightly as the activity of carbon is lowered.

Since in metallurgical reactions, interaction between several solutes has to be taken into account, some consideration will now be given to quaternary and more complex systems.

Sherman and Chipman[5] investigated the joint effects of two or more alloying elements on the activity coefficient of sulphur in a series of experiments at 1600° C. From their results the values of (Q_S^X) have been calculated in a manner already described; the brackets have been used to indicate that the measure of interaction is for systems having more than three components. The value of (Q_S^X) is calculated by the following empirical expression:

$$\log (Q_S^Y) = \log Q_S^{Y_1} + \log Q_S^{Y_2} + \log Q_S^{Y_3} \ldots \quad (14)$$

where X_1, X_2, X_3, . . . are Si, Al, C, etc. To test the validity of equation (14), Fig. 10 shows the values of $\log (Q_S^X)$, calculated from the above equation and Fig. 8, plotted against the values of $\log (Q_S^X)$ obtained directly from the results of Sherman and Chipman.[5] When the value of $\log (Q_S^X)$ is less than about 0·5, the calculated and observed values agree well with one another. In four of the melts, containing, in addition to other solutes, more than 2·0% Si ($N_{Si} > 0{\cdot}035$) linear relationship is not obeyed; this may be an indication of the limit of applicability of equation (14).

Recently, some work has been done on the solubility of graphite in Fe–Si–P melts[18] and it was shown that the plots of $\Delta N_C^{i,\,P}$ (for melts containing 1·26% P), and ΔN_C^{i} against the atom fraction of silicon did not give parallel curves, which indicates that the individual effects of phosphorus and silicon on the solubility of graphite in iron are not additive. In fact, for the given phosphorus concentration, i.e. 1·26%, the proportion of carbon displaced from a saturated solution by added silicon increases at a

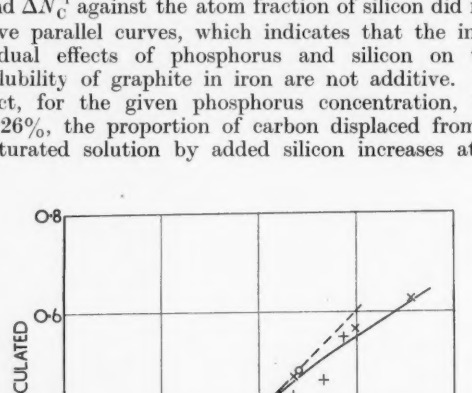


Fig. 10—Relationship between calculated and observed values of log (Q_Y^X)

Table I

THE VALUES OF LOG Q_Y^X AT VARIOUS CONCENTRATIONS OF THE SOLUTES X IN Fe–X–Y TERNARY SOLUTIONS

N_X, at. fr	log Q_Y^X								
	Si–C	C–Si	Cr–C	Si–S	Al–S	C–S	P–S	Cu–S	Mn–S
0·02	0·032	0·029	−0·037	0·080	0·072	0·066	0·062	−0·028	−0·040
0·04	0·067	0·061	−0·075	0·160	0·144	0·132	0·124	−0·056	−0·087
0·06	0·106	0·093	−0·111	0·243	0·220	0·204	0·182	−0·084	−0·146
0·08	0·141	0·130	−0·149	0·337	...	0·276	0·241	−0·112	−0·219
0·10	0·190	0·169	−0·185	0·444	...	0·360	0·305	−0·140	...
0·12	...	...	−0·220	0·569	...	0·444	0·372	−0·168	...
0·14	...	...	−0·255	0·721	...	0·538	0·445	...	...
0·16	...	...	−0·290	0·921	...	0·648	0·523	...	...
0·18	...	...	−0·325	...	...	0·762	...	...	...
0·20	...	...	−0·352	...	...	0·903	...	...	...
Temp., °C	1300	1420	← 1600 →						

much higher rate above approximately 0·04 atom fraction of silicon, i.e. about 2·1%.

CONCLUSIONS

The effect of an alloying element on the activity coefficient of a solute dissolved in iron can best be represented by the expression

$$Q_Y^X = \gamma_Y/\gamma_Y^Y$$

where γ_Y and γ_Y^Y are the activity coefficients of the solute Y in the ternary and binary systems at the same activity of Y. As evidenced by all the available data on various iron-based solid and liquid ternary systems, with the exception of Fe–Mn–C alloys, the term Q_Y^X is independent of the activity of the solute Y but is a continuous function of the concentration of the third element X at a given temperature. This allows the calculation of γ_Y over a wide composition range with only the few experimental results which are essential to evaluate the basic relationship between Q_Y^X and N_X.

When the activity coefficient factor is represented by the ratio $P_Y^X = \gamma_Y/\gamma_Y^Y$ at a fixed concentration of Y, then the value of P_Y^X, at a given temperature, is a function of the concentrations of the solutes X and Y.

It is indicated that in solutions where Henry's law is obeyed, $Q_Y^X = P_Y^X$.

In quaternary or more complex systems, the simultaneous effects of the various solutes on the activity coefficient factor of one of them can be represented in dilute solutions by the expression

$$(Q_Y^X) = Q_Y^{X_1} \cdot Q_Y^{X_2} \cdot Q_Y^{X_3} \ldots$$

where X_1, X_2, X_3 . . . etc. are the solutes whose effects on the activity coefficient of Y are under consideration.

Acknowledgment

The author wishes to thank Dr. J. Pearson for his helpful comments on this paper.

References

1. J. CHIPMAN: *Disc. Faraday Soc.*, 1948, No. 4, pp. 23–49.
2. C. WAGNER: "Thermodynamics of Alloys," p. 51: 1952, Cambridge, Mass., Addison-Wesley Press, Inc.
3. C. W. SHERMAN, H. I. ELVANDER, and J. CHIPMAN: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 334–340; *J. Met.*, 1950, vol. 2, Feb.
4. J. CHIPMAN and J. F. ELLIOTT: *Trans. Amer. Soc. Metals*, 1949, vol. 42A, p. 102.
5. C. W. SHERMAN and J. CHIPMAN: *Trans. Amer. Inst. Min. Met. Eng.*, 1952, vol. 194, pp. 597–602; *J. Met.*, 1952, vol. 4, June.
6. R. P. SMITH: *J. Amer. Chem. Soc.*, 1948, vol. 70, pp. 2724–2729.
7. F. D. RICHARDSON and W. E. DENNIS: *J. Iron Steel Inst.*, 1953, vol. 175, pp. 257–263.
8. E. T. TURKDOGAN: *Ibid.*, 1955, vol. 179, pp. 43–45.
9. J. CHIPMAN *et al.*: *Trans. Amer. Soc. Metals*, 1952, vol. 44, pp. 1215–1230.
10. E. T. TURKDOGAN and L. E. LEAKE: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 39–43.
11. J. CHIPMAN, J. C. FULTON, N. GOKCEN, and G. R. CASKEY: *Acta Met.*, 1954, vol. 2, pp. 439–450.
12. F. D. RICHARDSON: *J. Iron Steel Inst.*, 1953, vol. 175, pp. 33–51.
13. J. P. MORRIS and R. C. BUEHL: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 317–322; *J. Met*, 1950, vol. 2, Feb.
14. J. P. MORRIS and A. J. WILLIAMS: *Trans. Amer. Soc. Metals*, 1949, vol. 41, pp. 1425–1439.
15. E. T. TURKDOGAN and R. A. HANCOCK: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 155–159.
16. J. CHIPMAN and C. W. SHERMAN: *Rev. Mét.*, 1951, vol. 48, p. 613.
17. T. ROSENQVIST and E. M. COX: *Trans. Amer. Inst. Min. Met. Eng.*, 1950, vol. 188, pp. 1389–1393; *J. Met.*, 1950, vol. 2, Nov.
18. E. T. TURKDOGAN and L. E. LEAKE: *J. Iron Steel Inst.*, 1955, vol. 180, pp. 269–271.

Correction to Figures: In Figs. 8, 9, and 10, the expressions log (θ_Y^X), log (θ_S^X) should read log (Q_Y^X), log (Q_S^X)

Silicon and Manganese Reactions in Ferromanganese Blast-Furnace Processes

By E. T. Turkdogan

SYNOPSIS

An attempt has been made to discover the factors controlling the distribution of manganese and silicon between metal and slag phases under the conditions of ferromanganese production. Considerations based on a ferromanganese blast-furnace works' data indicate that, for a given lime/silica ratio, $(MnO\%)^2/[Mn\%]^2$ is directly proportional to the $[Si\%]/(SiO_2\%)$ ratio, and the proportionality factor decreases slightly as the silicon content of the metal decreases. By making use of some laboratory experimental results, it has been possible to calculate the activity coefficient of manganous oxide in blast-furnace-type slags. 1197

A SEARCH through available literature indicates that little research work has been done on the problems associated with the manufacture of ferromanganese in the blast-furnace. Investigations are now being carried out in these laboratories on the fundamentals of manganese-based melts. As a prelude to these researches some considerations have been given to the nature of the reactions occurring in a blast-furnace producing ferromanganese. Although, in principle, there is no difference between the performance of this type of furnace and that of one producing pig iron, the details of their working conditions differ noticeably. Among other things, one of the important problems is the prevention of the loss of manganese to the slag and its recovery from flue dust and slags. The purpose of this paper is to elucidate the conditions which control the distribution of manganese and silicon between manganese melts and slags.

FERROMANGANESE BLAST-FURNACE DATA

In order to keep a close check on the quality of the ferromanganese produced, it is general practice to analyse the metal from each cast for Mn, Fe, Si, P, S, and sometimes for carbon, and the slag for manganous oxide. Normally the furnace is tapped four times a day, and the four metal and slag samples are mixed and representative portions are analysed to give daily compositions; the daily slag samples are analysed for calcium oxide, manganous oxide, and silica. The weekly slag samples are, however, analysed for all the constituent oxides. The author has recently obtained some works' data from Dorman, Long and Co., Ltd.; the data are for October, November, and December, 1954, and for March, 1955. Incompleteness of the analysis of the individual slag samples makes it necessary to use the daily average analyses of the metal and slag samples, for the present considerations.

Table I is a summary of the data where the concentrations of alumina, ferrous oxide, magnesia, barium oxide, and sulphur are practically constant, the sum of which is about 20%.

It is well known that the distribution of manganese between metal and slag is dependent on the degree of oxidation of this element, and as a first approximation, the silicon content of the metal may be used as an indication of the oxygen potential of the system. According to the relationship shown in Fig. 1, where the concentration of Si in the metal is plotted against the Mn content of the slag, the loss of Mn to the slag is low only when the operating conditions favour high Si in the ferromanganese produced. The scatter of the points in Fig. 1 is not surprising, because such a plot by no means represents the true relationship between the compositions of the slag and metal phases with respect to Si and Mn. Nevertheless, the relationship in Fig. 1 provides at least an approximate measure of the state of affairs influencing the loss or recovery of Mn to and from the slag.

The other variables which could easily be responsible for the scatter of the points in Fig. 1 are the concentrations of SiO_2 in the slag and Mn in the metal. In Fig. 2 the ratio $(MnO\%)^2/[Mn\%]^2$ is plotted against the ratio $(SiO_2\%)/[Si\%]$. The excessive scatter of the points in Fig. 2 can be reduced very appreciably by grouping the data according to lime/silica ratios. It is quite definite that a low Mn distribution between slag and metal can be achieved when the CaO/SiO_2 ratio of the slag increases for a given $(SiO_2\%)/[Si\%]$. It is often assumed that in blast-furnace processes, whether producing ferromanganese or pig iron, a slag with a high basicity will give a better Mn recovery. However, the relationship in Fig. 2 illustrates the significant effect of another variable, namely $(SiO_2\%)/[Si\%]$ ratio, on the Mn reaction. This means that an

Table I

COMPOSITION RANGE COVERED BY THE DATA

Metal, wt-%						
	C	Si	S	P	Mn	Fe
About	7·0	0·4–3·2	0·03	0·3	76–80	11–15
Slag, wt-%						
SiO_2	Al_2O_3	FeO	MnO	CaO	MgO	
26–29	12–13	0·3–0·4	5–25	32–46	1·7–2·2	
		S	BaO			
		1·7–2·2	1–2			

Paper C/10/55 of the Chemistry Department of the British Iron and Steel Research Association, received 23rd July, 1955.

Dr. Turkdogan is Head of the Physical Chemistry Section of the Chemistry Department of B.I.S.R.A.

increased recovery of Mn from the slag by increasing the basicity will be offset by any increase in the ratio $(SiO_2)/[Si\%]$.

The scatter of the points about the lines drawn in Fig. 2 is still excessive and this may indicate the influence of another factor. Examination of the data showed that the term

$$J' = \frac{(MnO\%)^2}{[Mn\%]^2} \cdot \frac{[Si\%]}{(SiO_2\%)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

could be related to the silicon content of the metal for a given CaO/SiO_2 ratio of the slag; Fig. 3 shows such a relationship between log J' and Si% in the metal for the CaO/SiO_2 ratios 1·35, 1·45, and 1·55 (within the range of $\pm$ 0·05 in all cases). Considering that (i) the data used are only daily averages, (ii) the terms defining J' are given in weight percentages instead of activities, and (iii) the temperature of the metal in the furnace hearth may vary from one cast to another, the scatter of the points in Fig. 3 is not unusual and it is permissible to draw parallel lines through them; the value of log J' decreases as the concentration of Si in the metal is lowered. In order to represent the lines in Figs. 2 and 3 by a simple mathematical expression, the following procedure may be adopted. The values of J' extrapolated to 0% Si may be called J and have the following values depending on the CaO/SiO_2 ratio:

$J \times 10^3$	$CaO\%/SiO_2$
1·58	1·25
1·35	1·35
1·07	1·45
0·85	1·55
0·50	1·65

The plot of J against $CaO\%/SiO_2\%$ gives almost a straight line, which may be represented by the expression

$$J = 10^{-3}\left(-2{\cdot}83\,\frac{CaO\,\%}{SiO_2\,\%} + 5{\cdot}18\right) \quad \ldots\ldots\ldots (2)$$

The slope of the parallel lines in Fig. 3 is 0·07, and

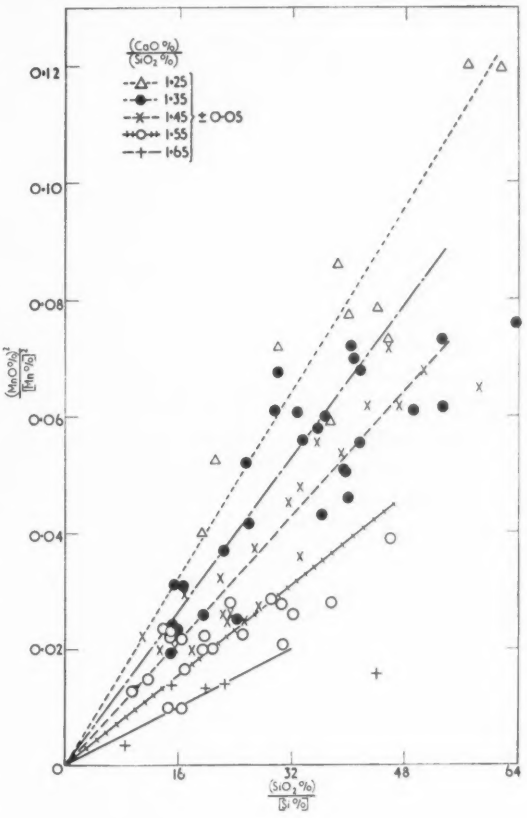


Fig. 2—Distributions of Si and Mn between slag and metal under the conditions of ferromanganese production

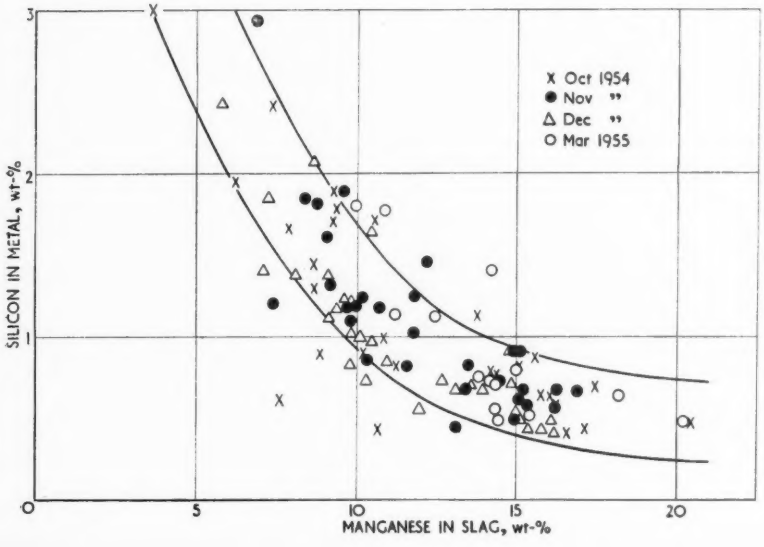


Fig. 1—Relationship between Si and Mn contents of ferromanganese and slag phases respectively

the following expression gives the values of log J':

$$\log J' = 0{\cdot}07\,[Si\,\%] + \log\left(-2{\cdot}83\,\frac{CaO\,\%}{SiO_2\,\%} + 5{\cdot}18\right) - 3{\cdot}0 \quad \ldots (3)$$

where J' is defined by equation (1). So far as practical requirements are concerned, equations (1) and (3) are the best way of representing the factors controlling the Si and Mn reactions in slag–metal systems in a ferromanganese-producing blast-furnace.

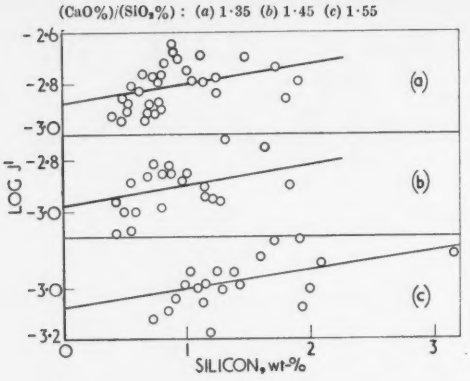


Fig. 3—log $J' = \log \frac{(\mathrm{MnO}\%)^2}{[\mathrm{Mn}\%]^2} \cdot \frac{[\mathrm{Si}\%]}{\mathrm{SiO_2}\%}$ related to the Si content of the metal for a given CaO/SiO_2 ratio

THERMODYNAMIC CONSIDERATIONS

Silicon and Manganese Reactions

The correlations so far sought between the slag and metal analysis data are of an empirical nature. However, it is desirable to investigate whether the expressions (1) and (3) have any physico-chemical significance.

One of the simplest ways of expressing the oxidation and reduction of Mn is

$$[\mathrm{Mn}] + \mathrm{CO}\ (g) = (\mathrm{MnO}) + [\mathrm{C}] \quad \ldots\ldots(4)$$

Although the metal in the hearth of the furnace may be assumed to be saturated with carbon, and therefore that the latter has unit activity, the partial pressure of CO within the vicinity of the hearth is not certain. There is also a further complication arising from the sluggishness of the carbon–oxygen reaction in molten metal,[1] and thus the concentrations of carbon and oxygen in the metal are those which would be in equilibrium with several atmospheres pressure of CO, although the total external pressure may be about 1–2 atm. Further evidence for this argument is given by the results of Goldman, Derge, and Philbrook[2] and Turkdogan, Hancock, and Pearson.[3] Moreover, when the Mn and S reactions are represented by the expression

$$\underset{\text{metal}}{[\mathrm{Mn}]} + [\mathrm{S}] = \underset{\text{slag}}{(\mathrm{Mn})} + (\mathrm{S}) \quad \ldots\ldots(5)$$

the relationship (S%)/[S%] and [Mn%]/(Mn%) obtained from works' data is the same as that given by the laboratory experiments,[1] although 'effective' CO pressure in the blast-furnace metal may be much greater than the 1 atm used in laboratory experiments. In other words, the equilibrium conditions of reaction (5) is independent of the 'effective' CO pressure in the melt.

In view of the above, the Mn and Si reaction may best be considered in the following form

$$(\mathrm{SiO_2}) + 2[\mathrm{Mn}] = 2(\mathrm{MnO}) + [\mathrm{Si}] \quad \ldots\ldots(6)$$

Choosing the pure liquid elements and oxides as the standard states, the free-energy change of reaction (6) is computed from reliable data[4–6] and found to be

$$\Delta G^\circ = 53{,}660 - 20{\cdot}83T \text{ cal} \quad \ldots\ldots(7)$$

which gives the following temperature function for the equilibrium constant

$$\log K = -\frac{11{,}730}{T} + 4{\cdot}553 \quad \ldots\ldots(8)$$

where K is given by

$$K = \frac{(N_{\mathrm{MnO}})^2}{[N_{\mathrm{Mn}}]^2} \cdot \frac{[N_{\mathrm{Si}}]}{(N_{\mathrm{SiO_2}})} \cdot \frac{(\gamma_{\mathrm{MnO}})^2}{[\gamma_{\mathrm{Mn}}]^2} \cdot \frac{[\gamma_{\mathrm{Si}}]}{(\gamma_{\mathrm{SiO_2}})} \quad \ldots\ldots(9)$$

or

$$K = K' \cdot \frac{(\gamma_{\mathrm{MnO}})^2}{[\gamma_{\mathrm{Mn}}]^2} \cdot \frac{[\gamma_{\mathrm{Si}}]}{(\gamma_{\mathrm{SiO_2}})} \quad \ldots\ldots(10)$$

K' is usually defined as the 'equilibrium ratio.'

Although the daily average slag samples, as mentioned earlier, were analysed only for the oxides of Ca, Mn, and Si, the number of gramme-moles per 100 g of weekly slags analysed completely is almost constant and can be taken as 1·62. The number of gramme-atoms per 100 g of ferromanganese is also nearly constant and its mean value is 2·32. The metal and slag composition can now be represented in terms of atom and mole fractions, and by a simple calculation the value of J' given by equation (1) can readily be converted to K', i.e.

$$K' = 1{\cdot}84\,J' \quad \ldots\ldots(11)$$

According to the works' data, the temperature of the metal in the runner immediately after the taphole is of the order of 1450° C, with an occasional variation of ± 75° C. At 1450° C, log $K = -2{\cdot}254$, and by combining equations (10) and (11) the following may be obtained

$$-2{\cdot}254 = \log 1{\cdot}84 + \log J' + \log \frac{(\gamma_{\mathrm{MnO}})^2}{[\gamma_{\mathrm{Mn}}]^2} \cdot \frac{[\gamma_{\mathrm{Si}}]}{[\gamma_{\mathrm{SiO_2}}]} \quad (12)$$

and replacing log J' by equation (3) it follows that

$$\log \frac{(\gamma_{\mathrm{MnO}})^2}{[\gamma_{\mathrm{Mn}}]^2} \cdot \frac{[\gamma_{\mathrm{Si}}]}{(\gamma_{\mathrm{SiO_2}})} = -\log\left(-2{\cdot}83\frac{\mathrm{CaO}\%}{\mathrm{SiO_2}\%} + 5{\cdot}18\right) + 0{\cdot}481 - 0{\cdot}07\,[\mathrm{Si}\%] \quad \ldots\ldots(13)$$

At present there are no relevant data for the evaluation of any of the activity coefficient terms on the left-hand side of the above expression. However, an attempt will be made to evaluate γ_{MnO} in blast-furnace slags containing less than 10% MnO.

Activity Coefficient of Manganese Oxide in Calcium Alumino-Silicates

Stukel and Cocubinsky[7] have recently determined the distribution of Mn between blast-furnace-type slag and metal by equilibrating these two phases in a graphite crucible, at 1 atm CO. They showed that the distribution ratio (MnO%)/[Mn%], for a given temperature, decreases as CaO/SiO_2 ratio increases, and for a given basicity, the Mn partition decreases with increase in temperature. Although these authors presented their results for technological use, a further study of their data will now be made, in view of the

need for more thermodynamic information on blast-furnace types of slag.

Consider the reaction

$$[Mn] + CO(g) = (MnO) + [C] \quad \ldots\ldots\ldots\ldots (14)$$

From the available data on the free energies of formation of MnO and CO from their elements in their standard states[4] the following may be obtained as the free-energy change of reaction (14).

$$\Delta G^\circ = -54{,}400 + 33{\cdot}58\ T \text{ cal} \quad \ldots\ldots\ldots\ldots (15)$$

The following are the standard states chosen: pure liquid Mn, 1 atm CO, pure liquid MnO, and β-graphite. The temperature-dependence of the equilibrium constant is given by

$$\log K = \frac{11{,}890}{T} - 7{\cdot}34 \quad \ldots\ldots\ldots\ldots (16)$$

where

$$K = \frac{(a_{MnO})}{[a_{Mn}]} \quad \ldots\ldots\ldots\ldots (17)$$

To evaluate the activity of MnO, it is necessary to know the activity of Mn in carbon-saturated iron. Such data unfortunately are not available, but the following approximation may be applied. Recently, Turkdogan *et al.*[8] determined the thermodynamic properties of Fe–C melts; Fig. 4 is plotted from their results and gives the relationship between the activity coefficient of iron and the composition of Fe–C melts at 1600° C. Consider now carbon-saturated Fe–Mn melts; because of the similarity in the electronic configurations of Fe and Mn atoms, it is permissible to assume that small percentages of Mn may not influence the activity coefficient of Fe. Furthermore, it is conceivable that the activity coefficient of Mn in these melts may not be very different from that of Fe; that is, Fe and Mn atoms in solution may be regarded additive to give the following expression for the total activity of the metallic elements:

$$\text{Activity of [Fe + Mn]} = \gamma_{Fe,Mn}[N_{Fe} + N_{Mn}] \quad \ldots\ldots (18)$$

It is unlikely that Mn–C interaction at low percentages of Mn should invalidate the contention referred to in equation (18).

Since temperature has only a small effect on the activities of the components of iron–carbon binary melts,[8] the curve in Fig. 4, drawn for 1600° C, could be applied to temperatures down to 1400° C without introducing any appreciable error. According to Fig. 4, the value of γ_{Fe}, which can be taken to be the same as $\gamma_{Fe,Mn}$ in the presence of small percentage of Mn, is 0·85; the activity of Mn in carbon-saturated iron is therefore equal to 0·85 N_{Mn}. In these melts the atom fraction of Mn (N_{Mn}) is directly proportional to its concentration in weight per cent; for convenience, therefore, the following expression may be used to convert the concentration of Mn to activity

$$a_{Mn} = 0{\cdot}0072\ [Mn\%] \quad \ldots\ldots\ldots\ldots (19)$$

Any error in the estimation of the Mn activity is not expected to be large enough, at low Mn concentrations, to affect the subsequent calculations.

By means of equations (16), (17), and (19), it is now possible to calculate the activity of MnO in slags in equilibrium with carbon-saturated iron containing a known concentration of Mn at any temperature.

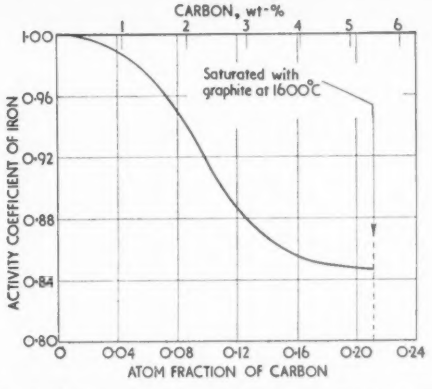


Fig. 4—Activity coefficient of iron in Fe–C binary melts at 1600° C; the standard state is pure liquid iron

These calculations have been applied to the data given by Stukel and Cocubinsky,[7] and the MnO activity of their slags is found to range from 0·02 to 0·16. Apart from six experiments, in all the other melts these authors used slags containing 16–45% CaO, 31–59% SiO_2, 8–31% Al_2O_3, 1–10% MnO, and less than 0·5% FeO; in the six melts mentioned, the slags also contained 5–11% MgO. In slags without magnesia there are four components which could influence the activity of MnO. In Fig. 5 activity coefficient of MnO is plotted against $CaO\%/SiO_2\%$ ratio for ranges of CaO concentrations. It has been observed that this activity coefficient is independent of the MnO content of the slag as indicated by the following few examples:

Experiment No.	MnO%	γ_{MnO}
10	6·40	0·055
11	7·74	0·055
14*B*	2·64	0·127
14*D*	9·71	0·121
15	4·85	0·123
22	3·56	0·089
31*D*	6·77	0·087

Since MnO does not affect its own activity coefficient within the range given, the slag composition can be recalculated to give $CaO\% + SiO_2\% + Al_2O_3\% = 100$. It is now possible to draw iso-activity coefficient curves of MnO in the $CaO–SiO_2–Al_2O_3$ pseudo-ternary system; these curves are given in Fig. 6 where the broken lines denote 1500° C liquidus iso-thermals. Uncertainty in the iso-activity lines is estimated to be about $\pm$ 0·01. The experimental results of Stukel and Cocubinsky given in Fig. 5 are for melts at 1450° and 1540° C; within this range, however, the effect of temperature on the MnO activity is not noticeable. The iso-activity coefficient curves in Fig. 6 should therefore apply within a range of 1400–1600° C.

The important features of the relationship in Fig. 6 are as follows:

(i) for a given CaO content, γ_{MnO} increases as Al_2O_3 is replaced by SiO_2

(ii) for a given SiO_2 content, γ_{MnO} increases as Al_2O_3 is replaced by CaO

(iii) for a given Al_2O_3 content, γ_{MnO} increases as SiO_2 is replaced by CaO at low CaO/SiO_2 ratios, but at higher basicities further increase in CaO content of the slag, at the expense of SiO_2, decreases γ_{MnO}.

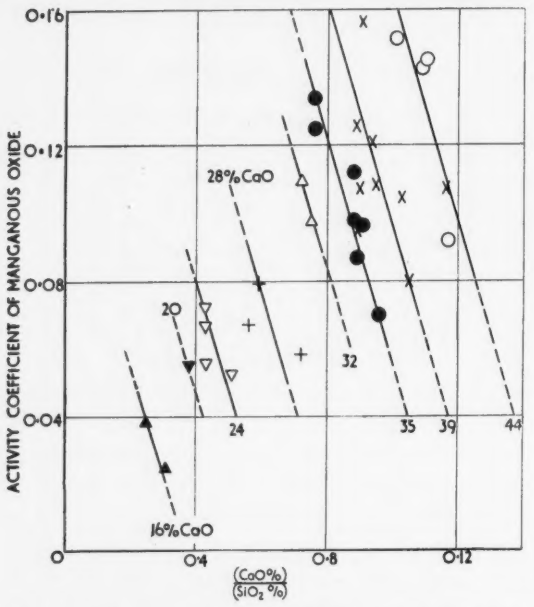


Fig. 5—Activity coefficient of MnO related to the CaO/SiO_2 ratio and the CaO content of the slag

From the first two items it follows that for a given CaO/SiO_2 ratio, γ_{MnO} decreases with increasing Al_2O_3 content of the slag; this suggests that there may be some bonding between the manganese cations and aluminate anions in the melt. In slags of low basicities, replacement of SiO_2 by CaO, at a given Al_2O_3 concentration, is expected to weaken the binding forces between manganese and silicate ions, thus increasing the activity of Mn in the slag. Increase in CaO content for a given Al_2O_3 concentration also reduces the interaction between aluminium and silicate ions so that, at higher CaO/SiO_2 ratios, aluminium cations are no longer stable and form aluminate anions, which in turn attract manganese cations, and consequently, the activity coefficient of MnO becomes less.

The point of inflexion of the iso-activity coefficient curves in Fig. 6 lies on a slightly curved line which, on extrapolation to the $CaO–SiO_2$ binary side, may intercept the 1500° C cristobalite liquidus iso-thermal; it is also indicated that at very low Al_2O_3 concentrations the curves tend to lose their point of inflexion so that in the $CaO–SiO_2$ binary system, γ_{MnO} may increase continuously as the composition of the melt changes from SiO_2 saturation towards the CaO-rich side.

In discussing the relationship in Fig. 6, reference should be made to iso-sulphide capacity curves drawn by Fincham and Richardson[9] for $CaO–SiO_2–Al_2O_3$ slags. The sulphide capacity defined by Fincham and Richardson[9] for slag–gas reactions and sulphur capacity used by the author[1] for slag–metal reactions are both a measure of the oxide ion activity of the slag. That is, sulphide or sulphur capacity is directly proportional to the oxide ion activity of the slag, the proportionality factor being the equilibrium constant for the sulphur reactions:

(*a*) Slag–gas: $\frac{1}{2}S_2(g) + (O) = (S) + \frac{1}{2}O_2(g)$.....(20)

(*b*) Slag–metal: $[S] + (O) = (S) + [O]$.....(21)

Returning to the sulphide diagrams of Fincham and Richardson, it is clear that increase in Al_2O_3 content of the slag for a given CaO/SiO_2 ratio decreases the oxide ion activity. Comparing this with Fig. 6, it follows that any change in slag composition, raising oxide ion activity, will increase γ_{MnO}.

To compute the activity of MnO in $CaO–Al_2O_3–SiO_2$ –MnO quaternary melts containing less than 10% MnO, it is necessary to know the atom fraction of MnO; this, however, can be obtained without having a complete slag analysis, for, as already pointed out, the number of moles in blast-furnace slags can be taken as 1·62. The percentage of MnO can therefore be converted to mole fraction by the following expression:

$$N_{MnO} = \frac{(MnO\,\%)}{54{\cdot}94 \times 1{\cdot}62} = \frac{(MnO\,\%)}{89} \quad .....(22)$$

The next stage is the recalculation of the slag composition so that $CaO\% + SiO_2\% + Al_2O_3\% = 100$; this enables the evaluation of γ_{MnO} to be made from Fig. 6.

CONCLUSIONS

From the average daily slag and metal analysis, it has been possible to correlate the distributions of manganese and silicon in metal and slag phases under ferromanganese-making conditions. At 1450° ± 75° C, this relationship may be represented by the following expression:

$$\log J' = 0{\cdot}07\,[Si\,\%] + \log\left(-2{\cdot}83\,\frac{CaO\,\%}{SiO_2\,\%} + 5{\cdot}18\right) - 3{\cdot}0$$

where $$J' = \frac{(MnO\,\%)^2}{[Mn\,\%]^2} \cdot \frac{[Si\,\%]}{(SiO)_2}$$

It is clear from the above expression that the basicity of the slag is not the sole measure of the manganese distribution between slag and metal. It is to be noted that for a given $[Si\%]/(SiO_2)$ ratio and silicon in the metal, the recovery of manganese from the slag increases with the CaO/SiO_2 ratio. If, on the other hand, increase of basicity is accompanied by a decrease in the $[Si\%]/(SiO_2)$ ratio, then there may be some loss of manganese from metal to the slag.

From thermodynamic considerations, the product of various activity coefficient terms has been calculated, thus

$$\log = \frac{(\gamma_{MnO})^2}{[\gamma_{Mn}]^2} \cdot \frac{[\gamma_{Si}]}{(\gamma_{SiO_2})} = -\log\left(-2{\cdot}83\,\frac{CaO\,\%}{SiO_2\,\%} + 5{\cdot}18\right) + 0{\cdot}481 - 0{\cdot}07\,[Si\,\%]$$

Separation of the various activity coefficient terms in this expression is not possible at present without an adequate knowledge on the interaction of solutes in carbon-saturated pure manganese and ferromanganese melts.

The activity coefficient of manganese oxide in calcium aluminosilicate slags containing less than 10% MnO has been calculated. It is pointed out that manganous oxide does not affect its own activity

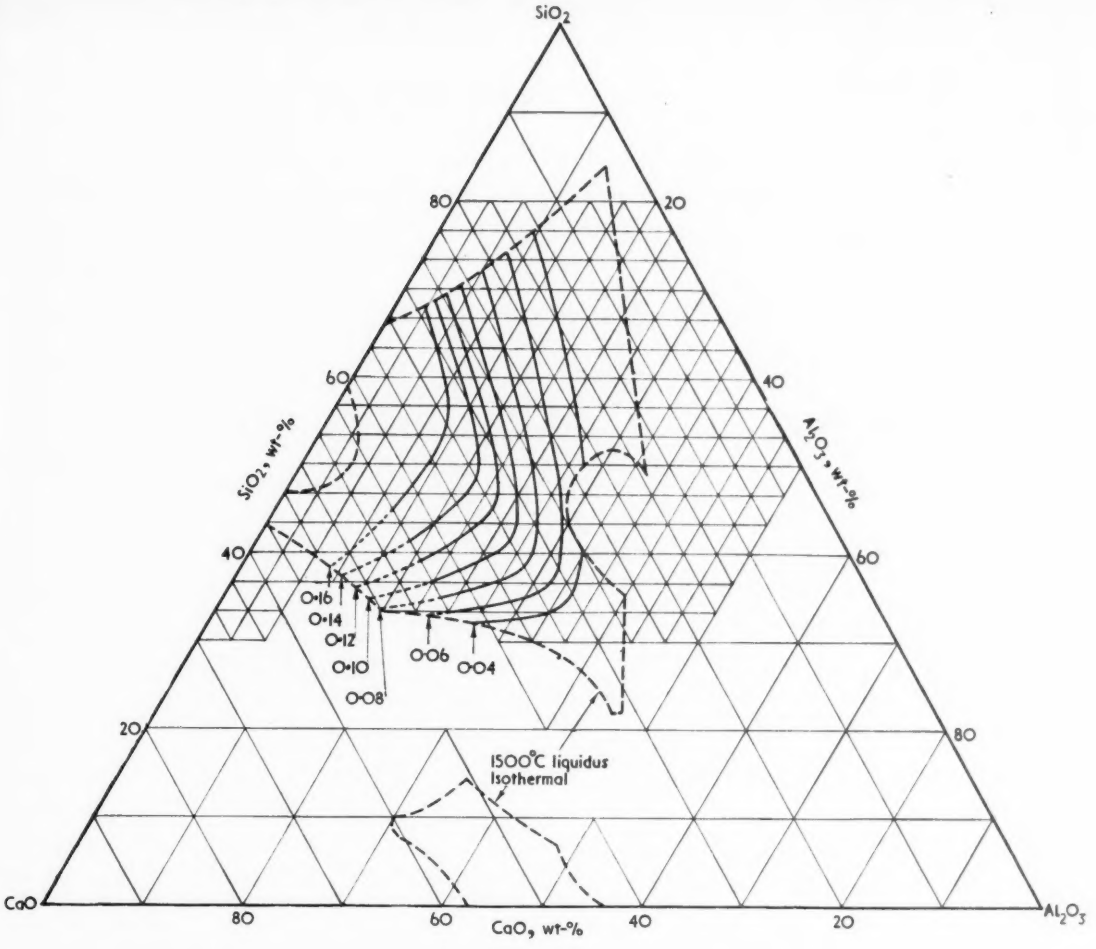


Fig. 6—Iso-activity coefficient curves of MnO drawn for $CaO–Al_2O_3–SiO_2$ pseudo-ternary system for the temperature range 1400–1600° C; the liquidus isothermal drawn is for 1500° C

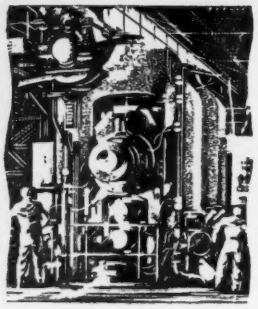
coefficient. From the iso-activity coefficient curves in $CaO–Al_2O_3–SiO_2$ pseudo-ternary system, it is clear that increase in alumina content for a given $CaO\%/SiO_2\%$ decrease γ_{MnO} as a result of a decrease in the oxide ion activity of the slag.

Acknowledgment

The author wishes to thank Dr. J. Pearson for his interest in this work, and Dorman, Long and Co., Ltd., for their works' data.

References

1. E. T. Turkdogan: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 147–154.
2. K. M. Goldman, G. Derge, and W. G. Philbrook: *Trans. Amer. Inst. Min. Met. Eng.*, 1954, vol. 200, pp. 534–540; *J. Met.*, 1954, vol. 6, May.
3. E. T. Turkdogan, R. A. Hancock, and J. Pearson: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 338–341.
4. F. D. Richardson and J. H. E. Jeffes: *Ibid.*, 1948, vol. 160, pp. 261–270.
5. J. Chipman *et al.*: *Acta Met.*, 1954, vol. 2, pp. 439–450.
6. F. D. Rossini *et al.*: "Selected Values of Chemical Thermodynamic Properties," ser. III: 1947 onwards, Washington, U.S. Department of Commerce, National Bureau of Standards.
7. J. E. Stukel and J. Cocubinsky: *Trans. Amer. Inst. Min. Met. Eng.*, 1954, vol. 200, pp. 353–356; *J. Met.*, 1954, vol. 6, Mar.
8. E. T. Turkdogan, L. E. Leake, and C. R. Masson: To be published in *Acta Met.*
9. C. J. B. Fincham and F. D. Richardson: *Proc. Roy. Soc.* 1954, vol. 223, pp. 40–62; (*see also*) *J. Iron Steel Inst.*, 1954, vol. 178, pp. 4–15.



AFFILIATED LOCAL SOCIETIES

Sheffield Society of Engineers and Metallurgists

Some Factors Affecting Spring Design

By W. R. Berry, M.Sc., Ph.D., M.I.Mech.E., F.R.I.C., F.I.M.

SYNOPSIS

The author draws attention to some of the lesser known factors which can affect the weight of a spring and suggests a method of specification for compression springs. The use of tension springs is recommended where an accurate rate is essential, and the use of deliberately produced very high initial tension as a means of enabling such springs to be preset (scragged) without resulting in open coils is suggested for the efficient use of material. Mention is made of shot-peening as a means of reducing weight in laminated springs.

Attention is drawn to various special sections produced for reducing the weight of laminated springs. In these sections the compression stress is increased without increasing the tensile stress.

Reference is made to recent work by the author on small helical torsion springs in which the use of patented wire enables higher design stresses to be used. Typical design charts are given. 1151

IT IS PROPOSED in this paper to consider some factors affecting spring design mainly from the point of view of making more efficient use of the material and thus saving weight.

TENSION SPRINGS

Tension springs are frowned upon for two reasons: (i) they tend to fail to danger and (ii) it is popularly supposed that they cannot be scragged without leaving the coils open and in consequence cannot make as efficient use of the material as can compression springs.

This is unfortunate, as the tension spring is the only type of helical coil spring for which an accurate rate can be guaranteed. In the case of a compression spring, once it is coiled and heat-treated, there is very little which can be done to compensate for the effect of uncontrollable variations in coil diameter, material section, and number of active coils on the rate.

For many applications, critical control of the rate of a spring is not necessary; in fact, where compression springs are used, rate should be disregarded and the spring defined by maximum and minimum loaded lengths, with agreed tolerances on the loads, and the free length left unspecified to permit adjustment to take advantage of the load limits to accommodate widely varying rates.

This method of specification for springs whose function is to store energy rather than to measure it seems logical; but some designers seem to be afraid of leaving the free length uncontrolled in case the spring should buckle in service. This is unlikely and can be avoided by the use of a chart based on Haringx's[1] recent work (Fig. 1). In tabular form the data are given in M.O.S. Design Data Sheets.[2]

Figure 2 shows the method of specification graphically. The theoretical slope of the spring is AB and the extremes of loaded length are l_1 and l_2 where the theoretical loads are P and W respectively. There must, for the spring to be practicable at all, be permissible tolerances on W and P, i.e. W_1 and W_2, and P_1 and P_2, and the tolerances must be the same percentage at each load.

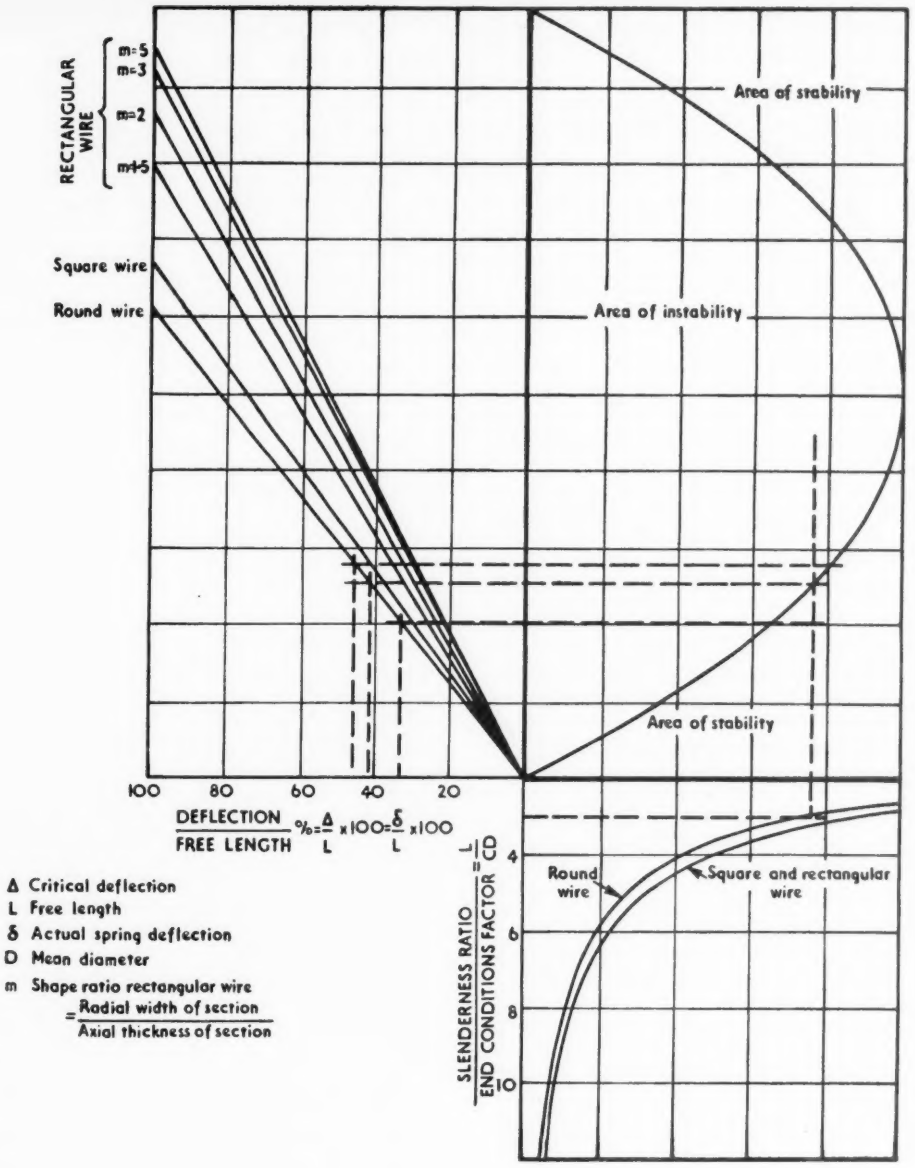
The largest free-length spring which could keep within the load limits would theoretically have the rate passing through W_2 and P_1 to A'.

It must not be forgotten that as the rate becomes less, the solid length of the spring increases, and the spring will probably be solid before it reaches l_2 in length with A' as the free length and the rate passing through W_2 and P_1.

By the time the specification is being drawn up,

This paper was presented to a meeting of the Sheffield Society of Engineers and Metallurgists held at the University Building, St. George's Square, Sheffield, on 15th March, 1954.

Dr. Berry is a consulting engineer and metallurgist.



Values of C

End conditions			Conventional illustration	C
Rotational		Lateral		
One end	Other end			
Fixed	Fixed	Guided		2·0
Fixed	Pinned	Guided		1·5
Pinned	Pinned	Guided		1·0
Fixed	Fixed	Unguided		1·0
Fixed	Pinned	Unguided		0·5

Fig. 1—Lateral stability chart for helical compression springs

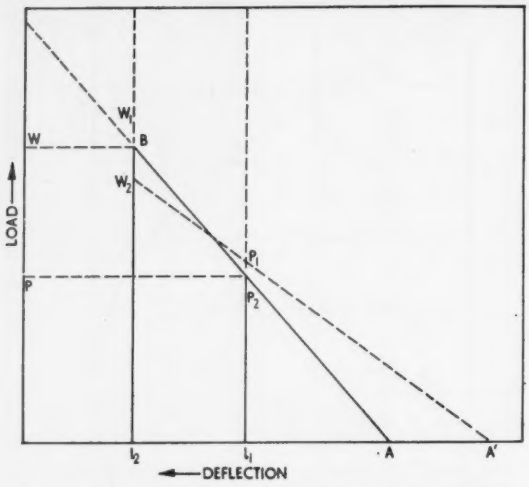


Fig. 2—Method of specification shown graphically

however, the limiting spring diameter and wire size will be known. It is a simple matter, therefore, to calculate the rate the spring would have when the solid length is the maximum which can be accommodated, and if this rate is plotted on the diagram so that the negative tolerance on W and the positive tolerance on P are the same percentage of their respective loads, it will be quickly seen what is the longest free length which could be accommodated within the tolerances on loads at l_1 and l_2 and the maximum available solid length.

From Fig. 1 (the chart based on Haringx's work), we can determine δ/L and L/CD where L is the longest value of the free length.

If L/CD is applied to the diagram the value of Δ/L will be found. If this exceeds δ/L by a reasonable factor of safety (say 10%), the free length can be left entirely unlimited for adjustment by the spring maker after the spring has been finished and irretrievable scrap avoided.

On the other hand, if Δ/L is less than δ/L, the free length must be limited to force δ/L to be less than Δ/L by say 10% and the amount of adjustment available for manufacture will, in consequence, be reduced.

There are, however, many applications where accurate rate is essential. Such applications as weighing devices and all cases where measuring by the spring is essential, e.g. springs for governors, electric pantographs, etc., are cases of this type and often of vital importance to the mechanism concerned.

For these purposes tension springs have great attractions. If a tension spring is made with screwed plugs or shackles, it is a simple matter to determine the rate on test and then to alter the number of active coils by screwing the plugs or shackles in or out to compensate for the effect of the uncontrollable variables, and ultimately to adjust the spring to the required rate with any desired degree of accuracy.

Unfortunately, however, the two objections of failure to danger and inefficient use of material militate against the adoption of tension springs for important functions, and it seems worthwhile to consider what can be done about these objections.

So far as failure to danger is concerned, it is often possible to minimize this by suitable arrangement of limiting stops and even a compression spring, although it tends to jam, ceases to function in the required manner when it breaks and can cause danger.

The popular impression that it is not practicable to scrag tension springs without opening the coils is largely a fallacy, but many designers are not aware of this.

It is a comparatively simple matter with round-bar tension springs to create a state of very high initial tension equivalent to a stress of at least 50–60% of the torsional elastic limit. This is shown in Fig. 3.

The upper curve is a load/extension test of such a tension spring with high initial tension and shows that the initial tension (actually 22 lb) is 58% of the load at the elastic limit (i.e. 38 lb).

It is, however, a popular impression that such high initial tension can only be obtained from springs cold-coiled from hard-drawn wire, and that in consequence such springs are confined to small sizes of wire and, therefore, comparatively light loads.

This again is a fallacy. Such high initial tension springs are regularly made from fully heat-treated chrome vanadium spring steel of $\frac{1}{2}$-in. dia. and have been made from $\frac{5}{8}$-in. dia. bar of the same steel. There is no reason why they cannot be made from very much heavier materials.

There is, of course, a trick here. One method is first of all to wind an open-ended large pitch compression spring and fully heat-treat it, and then to turn it inside out to form a tension spring, which is surprisingly easy, provided that such materials can be obtained in lengths long enough.

High initial tension alone is extremely useful where a spring has to be accommodated in a confined space, but it can also be used to enable a tension spring to be effectively scragged and overcome the objection usually levelled at tension springs.

If such a spring is stretched until it yields, provided that it is not allowed to yield sufficiently to remove all the initial tension, the apparent elastic limit can be

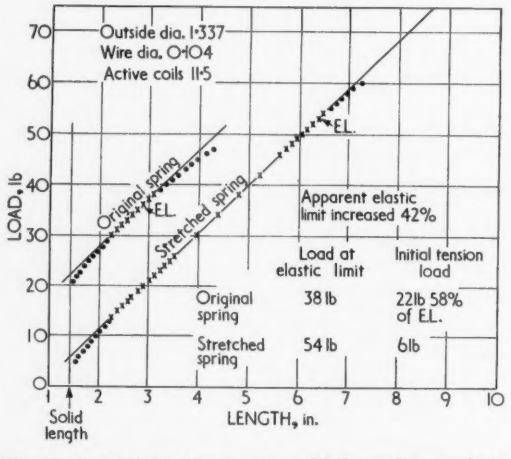


Fig. 3—Load/deflection tests, initial tension springs

increased very greatly and the coils will still be tight on release of the scragging force.

The lower curve on Fig. 3 is the curve obtained from the same spring after it has been stretched to remove most but not all of the initial tension. The load at the elastic limit has gone up from 38 lb to 54 lb, i.e. about 42%, which is approaching what can be done with compression springs by scragging. There is still, however, 6 lb of initial tension keeping the coils closed when the spring is free.

It is, therefore, possible to scrag tension springs effectively, and they need not be inefficient as popularly supposed. Owing to the ease with which the rate can be adjusted after the spring is made, such springs are the ones which should be used where the rate of the spring is important.

LAMINATED SPRINGS

The author has often been asked if something cannot be done to reduce the weight of laminated springs and consequently to improve the efficiency of the use of material.

There is a great deal of rather loose talk about the improvement in the efficient use of material by changing to torsion bars or coil springs for vehicle suspension. For instance, in a recent publication,[3] it is stated that the energy stored per pound of spring material in inch pounds is:

Torsion bars	1000–1500
Leaf springs	300–450

In other words, this publication is suggesting that torsion bars are over three times as efficient as laminated springs. This is most misleading. The only fair way to compare the efficiencies of different types of springs is to compare the resilience or maximum energy storage capacity when the maximum stress reaches the elastic limit of the material.

Table I gives the resilience formulæ for tension bars, torsion bars, and laminated springs, on the usual assumption that the laminated spring is of trapezoidal profile.

Table I

NORMAL RESILIENCE FORMULÆ FOR VARIOUS SPRINGS

Type of Spring	Type of Loading	Resilience Formula	Relative Energy Storage Capacity per Unit Volume (Tension Bar = Unity × Stress²)
Tension bar	Tension	$\frac{F^2V}{2E}$	$1\ F^2$
Round bar in torsion	Torsion	$\frac{f^2V}{4G}$	$1{\cdot}3\ f^2$
Laminated spring (correctly graded plate lengths)	Bending	$\frac{F^2V}{6E}$	$0{\cdot}33\ F^2$

F = Tensile stress
V = Volume of steel
E = Modulus of elasticity (30×10^6 lb/in² for steel)
f = Torsional stress
G = Modulus of rigidity ($11{\cdot}4 + 10^6$ lb/in² for steel)

Table II

COMPARISON OF ENERGY STORAGE CAPACITY OF VARIOUS SPRINGS

Type of Spring	Comparative Energy Storage Capacity at Elastic Limit	Comparative Energy Storage Capacity at Complete Yield
Tension bar	1	1
Round bar in torsion	0·43	0·77
Laminated spring (correctly graded plate lengths)	0·33	0·75

The formulæ in the third column cannot be compared directly but dividing out by $V/2E$ and evaluating E and G gives the energy storage per pound of steel in terms of stress compared with the tension bar, as shown in the fourth column.

If the numerical values of the stresses were identical (which is a completely unjustifiable assumption) the torsion bar would appear almost four times as efficient as the laminated spring, which may perhaps explain the published comparisons. Also, the torsion bar would appear to be more efficient than the tension bar, which is certainly not true. The stresses are not of the same character and consequently not comparable numerically.

The only reasonable comparison is when the stresses are the elastic limits, giving the maximum energy storage capacity of the different type of springs.

The maximum strain energy theory shows that the relation between the elastic limits in tension and torsion is

$$Fe = fe\sqrt{\frac{E}{G}}$$

where Fe = elastic limit in tension
fe = elastic limit in torsion
E = modulus of elasticity
G = modulus of rigidity

which for steel with $E = 30 \times 10^6$ and $G = 11{\cdot}5 \times 10^6$ gives:

$$Fe = 1{\cdot}622\ fe$$

Timoshenko,[4] based on Haber's works, shows that the relation is more truly

$$Fe = fe\sqrt{3} = 1{\cdot}732\ fe$$

and this latter figure seems to agree with test data much more closely than the former.

Before the true maximum energy storage capacities can be compared it is necessary to replace fe^2 by $Fe^2/3$, and to cancel out Fe^2 to obtain the true numerical comparison which is given in the second column of Table II.

It will thus be seen that the torsion bar is only 30% more efficient than the laminated spring if operated under comparable conditions.

Wahl[5] takes this still further and points out that if the springs are pre-stressed to the point of complete yield, the apparent elastic limit (i.e. the load at which yielding commences) is increased 50% in the case of

rectangular bars in bending and only 33⅓% in the case of round bars in torsion, so that the figures in the second column of this table require multiplying by $(1{\cdot}5)^2$, i.e. 2·25 in the case of laminated springs and $(4/3)^2$, i.e. 1·8 in the case of the torsion bar, which is done in the third column and shows that a fully scragged laminated spring should be approximately as efficient as the torsion bar.

There may be some argument about the last column on the grounds that it may not be possible to scrag to the point of complete yield, but there can be no doubt that the second column is the true theoretical comparison.

In the laminated spring, however, there is more dead material due to centre clamps than in torsion bars, and the actual comparison will not be as favourable to the laminated spring as the theoretical one; but it certainly will not be greatly different and not reach anything like the figures suggested in the published comparison.

It would appear that in the published comparison the springs compared are not being used under comparable conditions and it is, therefore, misleading.

In an actual torsion bar which is stated to have a nominal bump stress of 140,000 lb/in² in torsion the comparable tensile stress would be $\sqrt{3}$ times this figure, i.e. 243,000 lb/in² or 109 tons/in² tensile stress for a laminated spring operated under comparable stress conditions. Actually most laminated springs as at present used are operated at 60 tons/in² bump stress, i.e. the stress corresponding to the British Standard Test Deflection $L^2/900t$ where L is length of longest plate and t the thickness of the plates, both in inches.

The torsion bar was hardened and tempered to Rockwell C 49 (465 Brinell), whereas most laminated spring plates are tempered to about 400 Brinell.

It is obvious, therefore, that the springs are not performing the same functions and are not comparable.

The laminated spring is normally called upon not only to operate as a spring but also as a strut to hold the axles on to the vehicle and to take the starting and braking torques. The torsion bar is operated purely as a spring and additional fittings have to be used for the other purposes the laminated spring is expected to fulfil.

If a comparison is to be made the laminated spring should only be expected to perform the function of a spring, when it could be made very much more efficient and approach closely to the efficiency of a torsion bar.

Nevertheless it would, in many instances, be advantageous if the weight of laminated springs could be reduced.

From the resilience formula

$$\omega = \frac{F^2V}{6E}$$

for laminated springs of trapezoidal profile, it is obvious that reducing the weight (or volume) of material in a normal nominal flat section increases the maximum stress to which the spring will be subjected in service.

Further, when replacing an existing spring by a lighter one in a given suspension it is necessary to maintain the same rate per inch of movement and the same maximum movement from bump to rebound so that the mean or static load stress must increase by the same percentage as the maximum stress, and the stress range will increase by the same percentage.

The question therefore arises as to what effect such increase in mean stress and stress range would have on the fatigue life under various conditions. Naturally the effect on a plain plate would be to reduce life. But it is now well known that shot peening will very greatly increase life under the same conditions of mean stress and stress range, so that it would seem profitable to investigate whether shot peening would enable the mean stress and stress range to be increased without reduction in life. The author hopes to publish the results of such an investigation shortly and cannot anticipate publication except to say that under certain conditions it seems likely that shot peening can be used in the manner indicated.

While on the subject of reduction of weight of laminated spring plates, attention should be drawn to special sections. In the normal theoretical rectangular plate one face is subjected to tensile stresses only, while the other face is subjected to compressive stresses only, and the character of the stresses never reverses. It is generally accepted that fatigue failures are only caused by tensile stresses, so that it should be possible to increase the compressive stress on the compression face without affecting the fatigue life.

The removal of metal from some portion of the compression face up to the neutral axis raises the neutral axis and also alters the moment of inertia, and the resulting plate will not replace the original rectangular plate in a given spring. However, if metal is added on the remainder of the compression face, it restores the moment of inertia and tends to restore the neutral axis to its original position. The centre of gravity of the added material will, however, be considerably further from the neutral axis than the centre of gravity of the metal removed. In consequence, less metal will have to be added to compensate for the metal removed and an overall reduction in weight will result without having altered the moment of inertia or increased the tensile stress on the tension face of the plate and without having affected the fatigue life of the plate.

Sections have been produced on this principle in the U.S.A. where they have achieved some popularity but they have not found much favour in the U.K.

Lipson[6] derived an interesting expression for comparing the overall efficiency of such sections. From the normal basic formulæ for load and deflection in

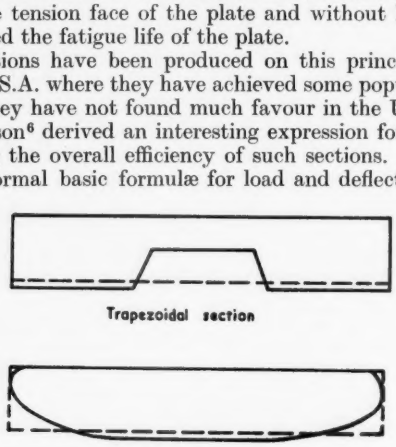


Fig. 4—Trapezoidal and parabolic sections

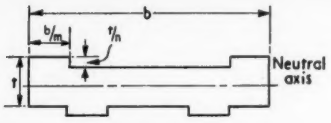


Fig. 5—Asspi section

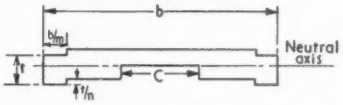


Fig. 6—Interlocking characteristics on single-grooved section

terms of stress and dimensions it is simple algebra to show that:

Work done per unit volume per unit stress

$$= \frac{I}{Ay^2} \times \frac{1}{4E} = \frac{I}{Ay^2} \times \text{Constant}$$

where I is the moment of inertia of the section, A the cross-sectional area, y the distance of the tension face from the neutral axis, and E Young's Modulus.

Lipson, therefore, considers that the term I/Ay^2 is a measure of the efficiency of the section, which is, of course, theoretically correct. (Whether this is the practical efficiency will be dealt with later in the paper.)

On this basis the theoretical rectangle must have an efficiency factor of $\frac{1}{3}$.

Two popular special sections in the U.S.A. are the trapezoidal groove section due to Wallace of the Eaton Manufacturing Co. (sometimes known as the Eaton Section), and the parabolic section due to Figgie and Hendrickson of the Mather Spring Co. These are shown in theoretical outline in Fig. 4, the original rectangular section being superimposed as shown by the dotted lines where the sections diverge.

The Americans have calculated the efficiency factors for these sections in practical form (rounded edges and trapezoidal groove), in comparison with the equivalent theoretical rectangle, as 116% for the trapezoidal section with groove one-third of width of section and 113% for the parabolic section.

This does not seem to be the true picture and is liable to lead to unexpected troubles if overall efficiency only is considered.

If one considers the terms y and A in the efficiency formulæ (I must be that of the equivalent rectangle the plate is to replace), for the trapezoidal section y is 96·5% of that for the original rectangle and A is 88% of that of the original section, but the maximum thickness has been increased 107·4%, thus giving an increase in the compressive stress of about 18%. In the case of the parabolic section y is 98% of original value, A is 93% and the compressive stress is increased about 15%.

A reduction in weight (the factor A) has, therefore, been obtained at the expense of increasing the compressive stress and slightly reducing the tensile stress. The increased compressive stress may cause yielding but can be accommodated by efficient scragging, which will also be beneficial to the tension face.

A special section originating in Sweden known as the Asspi section has achieved some popularity on Continental railways owing to its interlocking characteristics preventing lateral movement of the plate. Such a section also has some advantage from the point of view of lubrication. This section is shown theoretically in Fig. 5.

The width of the lugs in the original section was fixed at one-sixth of the width of the plate (m in Fig. 5 is, therefore, 6), and the depth of the lugs was arbitrarily fixed as 2·4 mm, i.e. 0·1 in. Choosing the arbitrary figures for width and depth of lugs as done in the original patent means every section has a different efficiency factor. The author has therefore explored the effect of variations in width and depth of lugs by giving varying values to m and n shown in Fig. 5.

This exploration is summarized in Table III. It will be seen (as is, of course, obvious from the fact that lugs are sticking up on the tension face), that in every case the tensile stress is higher than in the flat section replaced, and that the stress increases with increase in m and decreases with increase in n as would be expected.

The weight, on the other hand, is less than the flat

Table III

EFFECT OF VARIATIONS ON ASSPI SECTION

m	n	Stress Factor $y/y_F = t/t_F$	Weight Factor A/A_F	Efficiency Factor E/E_F	Rectangular Section Same Stress	
					Weight Factor $\frac{A'_F}{A_F}$	Relation Asspi Rectangle $\frac{A}{A'_F}$
4	3	1·245	0·5000	1·290	0·6454	0·7749
	4	1·208	0·5714	1·199	0·6855	0·8335
	5	1·180	0·6250	1·148	0·7181	0·8704
	6	1·155	0·6667	1·123	0·7496	0·8896
	7	1·136	0·7000	1·108	0·7749	0·9035
	8	1·120	0·7271	1·094	0·7973	0·9120
5	3	1·332	0·5172	1·090	0·5636	0·9177
	4	1·281	0·5882	1·035	0·6095	0·9649
	5	1·236	0·6409	1·021	0·6546	0·9790
	6	1·200	0·6817	1·017	0·6944	0·9897
	7	1·174	0·7143	1·016	0·7254	0·9849
	8	1·153	0·7408	1·016	0·7523	0·9847
6	3	1·408	0·5294	0·9523	0·5047	1·049
	4	1·339	0·6000	0·9294	0·5577	1·076
	5	1·279	0·6521	0·9365	0·6112	1·068
	6	1·235	0·6923	0·9469	0·6558	1·055
	7	1·201	0·7241	0·9563	0·6934	1·044
	8	1·176	0·7500	0·9640	0·7228	1·038
7	3	1·474	0·5384	0·8549	0·4603	1·169
	4	1·387	0·6087	0·8543	0·5195	1·171
	5	1·314	0·6604	0·8762	0·5792	1·140
	6	1·262	0·6998	0·8971	0·6277	1·115
	7	1·224	0·7313	0·9135	0·6674	1·096
	8	1·196	0·7568	0·9239	0·6988	1·082

rectangular bars in bending and only 33⅓% in the case of round bars in torsion, so that the figures in the second column of this table require multiplying by $(1{\cdot}5)^2$, i.e. 2·25 in the case of laminated springs and $(4/3)^2$, i.e. 1·8 in the case of the torsion bar, which is done in the third column and shows that a fully scragged laminated spring should be approximately as efficient as the torsion bar.

There may be some argument about the last column on the grounds that it may not be possible to scrag to the point of complete yield, but there can be no doubt that the second column is the true theoretical comparison.

In the laminated spring, however, there is more dead material due to centre clamps than in torsion bars, and the actual comparison will not be as favourable to the laminated spring as the theoretical one; but it certainly will not be greatly different and not reach anything like the figures suggested in the published comparison.

It would appear that in the published comparison the springs compared are not being used under comparable conditions and it is, therefore, misleading.

In an actual torsion bar which is stated to have a nominal bump stress of 140,000 lb/in² in torsion the comparable tensile stress would be $\sqrt{3}$ times this figure, i.e. 243,000 lb/in² or 109 tons/in² tensile stress for a laminated spring operated under comparable stress conditions. Actually most laminated springs as at present used are operated at 60 tons/in² bump stress, i.e. the stress corresponding to the British Standard Test Deflection $L^2/900t$ where L is length of longest plate and t the thickness of the plates, both in inches.

The torsion bar was hardened and tempered to Rockwell C 49 (465 Brinell), whereas most laminated spring plates are tempered to about 400 Brinell.

It is obvious, therefore, that the springs are not performing the same functions and are not comparable.

The laminated spring is normally called upon not only to operate as a spring but also as a strut to hold the axles on to the vehicle and to take the starting and braking torques. The torsion bar is operated purely as a spring and additional fittings have to be used for the other purposes the laminated spring is expected to fulfil.

If a comparison is to be made the laminated spring should only be expected to perform the function of a spring, when it could be made very much more efficient and approach closely to the efficiency of a torsion bar.

Nevertheless it would, in many instances, be advantageous if the weight of laminated springs could be reduced.

From the resilience formula

$$\omega = \frac{F^2V}{6E}$$

for laminated springs of trapezoidal profile, it is obvious that reducing the weight (or volume) of material in a normal nominal flat section increases the maximum stress to which the spring will be subjected in service.

Further, when replacing an existing spring by a lighter one in a given suspension it is necessary to maintain the same rate per inch of movement and the same maximum movement from bump to rebound so that the mean or static load stress must increase by the same percentage as the maximum stress, and the stress range will increase by the same percentage.

The question therefore arises as to what effect such increase in mean stress and stress range would have on the fatigue life under various conditions. Naturally the effect on a plain plate would be to reduce life. But it is now well known that shot peening will very greatly increase life under the same conditions of mean stress and stress range, so that it would seem profitable to investigate whether shot peening would enable the mean stress and stress range to be increased without reduction in life. The author hopes to publish the results of such an investigation shortly and cannot anticipate publication except to say that under certain conditions it seems likely that shot peening can be used in the manner indicated.

While on the subject of reduction of weight of laminated spring plates, attention should be drawn to special sections. In the normal theoretical rectangular plate one face is subjected to tensile stresses only, while the other face is subjected to compressive stresses only, and the character of the stresses never reverses. It is generally accepted that fatigue failures are only caused by tensile stresses, so that it should be possible to increase the compressive stress on the compression face without affecting the fatigue life.

The removal of metal from some portion of the compression face up to the neutral axis raises the neutral axis and also alters the moment of inertia, and the resulting plate will not replace the original rectangular plate in a given spring. However, if metal is added on the remainder of the compression face, it restores the moment of inertia and tends to restore the neutral axis to its original position. The centre of gravity of the added material will, however, be considerably further from the neutral axis than the centre of gravity of the metal removed. In consequence, less metal will have to be added to compensate for the metal removed and an overall reduction in weight will result without having altered the moment of inertia or increased the tensile stress on the tension face of the plate and without having affected the fatigue life of the plate.

Sections have been produced on this principle in the U.S.A. where they have achieved some popularity but they have not found much favour in the U.K.

Lipson[6] derived an interesting expression for comparing the overall efficiency of such sections. From the normal basic formulæ for load and deflection in

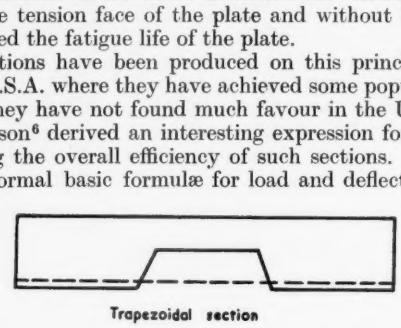


Fig. 4—Trapezoidal and parabolic sections

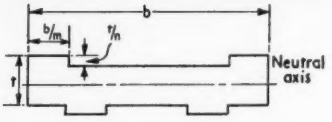


Fig. 5—Asspi section

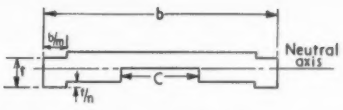


Fig. 6—Interlocking characteristics on single-grooved section

terms of stress and dimensions it is simple algebra to show that:

Work done per unit volume per unit stress

$$= \frac{I}{Ay^2} \times \frac{1}{4E} = \frac{I}{Ay^2} \times \text{Constant}$$

where I is the moment of inertia of the section, A the cross-sectional area, y the distance of the tension face from the neutral axis, and E Young's Modulus.

Lipson, therefore, considers that the term I/Ay^2 is a measure of the efficiency of the section, which is, of course, theoretically correct. (Whether this is the practical efficiency will be dealt with later in the paper.)

On this basis the theoretical rectangle must have an efficiency factor of $\frac{1}{3}$.

Two popular special sections in the U.S.A. are the trapezoidal groove section due to Wallace of the Eaton Manufacturing Co. (sometimes known as the Eaton Section), and the parabolic section due to Figgie and Hendrickson of the Mather Spring Co. These are shown in theoretical outline in Fig. 4, the original rectangular section being superimposed as shown by the dotted lines where the sections diverge.

The Americans have calculated the efficiency factors for these sections in practical form (rounded edges and trapezoidal groove), in comparison with the equivalent theoretical rectangle, as 116% for the trapezoidal section with groove one-third of width of section and 113% for the parabolic section.

This does not seem to be the true picture and is liable to lead to unexpected troubles if overall efficiency only is considered.

If one considers the terms y and A in the efficiency formulæ (I must be that of the equivalent rectangle the plate is to replace), for the trapezoidal section y is 96·5% of that for the original rectangle and A is 88% of that of the original section, but the maximum thickness has been increased 107·4%, thus giving an increase in the compressive stress of about 18%. In the case of the parabolic section y is 98% of original value, A is 93% and the compressive stress is increased about 15%.

A reduction in weight (the factor A) has, therefore, been obtained at the expense of increasing the compressive stress and slightly reducing the tensile stress. The increased compressive stress may cause yielding but can be accommodated by efficient scragging, which will also be beneficial to the tension face.

A special section originating in Sweden known as the Asspi section has achieved some popularity on Continental railways owing to its interlocking characteristics preventing lateral movement of the plate. Such a section also has some advantage from the point of view of lubrication. This section is shown theoretically in Fig. 5.

The width of the lugs in the original section was fixed at one-sixth of the width of the plate (m in Fig. 5 is, therefore, 6), and the depth of the lugs was arbitrarily fixed as 2·4 mm, i.e. 0·1 in. Choosing the arbitrary figures for width and depth of lugs as done in the original patent means every section has a different efficiency factor. The author has therefore explored the effect of variations in width and depth of lugs by giving varying values to m and n shown in Fig. 5.

This exploration is summarized in Table III. It will be seen (as is, of course, obvious from the fact that lugs are sticking up on the tension face), that in every case the tensile stress is higher than in the flat section replaced, and that the stress increases with increase in m and decreases with increase in n as would be expected.

The weight, on the other hand, is less than the flat

Table III

EFFECT OF VARIATIONS ON ASSPI SECTION

m	n	Stress Factor $y/y_F = t/t_F$	Weight Factor A/A_F	Efficiency Factor E/E_F	Rectangular Section Same Stress	
					Weight Factor $\frac{A'_F}{A_F}$	Relation Asspi Rectangle $\frac{A}{A'_F}$
4	3	1·245	0·5000	1·290	0·6454	0·7749
	4	1·208	0·5714	1·199	0·6855	0·8335
	5	1·180	0·6250	1·148	0·7181	0·8704
	6	1·155	0·6667	1·123	0·7496	0·8896
	7	1·136	0·7000	1·108	0·7749	0·9035
	8	1·120	0·7271	1·094	0·7973	0·9120
5	3	1·332	0·5172	1·090	0·5636	0·9177
	4	1·281	0·5882	1·035	0·6095	0·9649
	5	1·236	0·6409	1·021	0·6546	0·9790
	6	1·200	0·6817	1·017	0·6944	0·9897
	7	1·174	0·7143	1·016	0·7254	0·9849
	8	1·153	0·7408	1·016	0·7523	0·9847
6	3	1·408	0·5294	0·9523	0·5047	1·049
	4	1·339	0·6000	0·9294	0·5577	1·076
	5	1·279	0·6521	0·9365	0·6112	1·068
	6	1·235	0·6923	0·9469	0·6558	1·055
	7	1·201	0·7241	0·9563	0·6934	1·044
	8	1·176	0·7500	0·9640	0·7228	1·038
7	3	1·474	0·5384	0·8549	0·4603	1·169
	4	1·387	0·6087	0·8543	0·5195	1·171
	5	1·314	0·6604	0·8762	0·5792	1·140
	6	1·262	0·6998	0·8971	0·6277	1·115
	7	1·224	0·7313	0·9135	0·6674	1·096
	8	1·196	0·7568	0·9239	0·6988	1·082

Table IV

COMPARISON OF STANDARD CONCAVE SECTION WITH GROOVED SECTION

Terms	Normal Concave Section	Square Edges		Round Edges	
		Interlocking Section	Single Groove Section	Interlocking Section	Single Groove Section
Nominal size, in.	$2\frac{1}{2} \times \frac{5}{16}$	$2\frac{1}{2} \times 0{\cdot}3118$	$2\frac{1}{2} \times 0{\cdot}3469$	$2\frac{1}{2} \times 0{\cdot}3118$	$2\frac{1}{2} \times 0{\cdot}3469$
Cross-section area, in^2	0·7614	0·5571	0·5067	0·5487	0·5963
Weight saved, %		26·82	20·31	27·93	21·70
Moment of inertia, in^4	0·005962	0·005890	0·005732	0·005800	0·005720
Tensile stress factor y, in.	0·1563	0·1542	0·1422	0·1527	0·1417
Bridge thickness, in.		0·1386	0·1386	0·1386	0·1386
Variation of I, %		−1·19	−3·82	−2·71	−4·04
Variation of y, %		−1·3	−8·99	−2·28	−9·33
Overall efficiency	0·3207	0·4445	0·4673	0·4533	0·4779
Overall efficiency, %	100	138·7	145·7	141·4	149·0

section replaced and the saving reduces with increase in m and also with increase in n.

Therefore, unless it is possible to tolerate an increase in tensile stress this section cannot be used to replace a given rectangular plate.

The Asspi section has, however, been used with some success on Continental railways and presumably, therefore, the conditions on such railway springs was such as to enable a higher tensile stress to be used without running into trouble due to fatigue failures.

If this is so, in these cases it should have been possible to use higher tensile stresses in the original rectangular plates; and since a laminated spring consists of a number of plates, it should be possible to re-design the original spring with fewer and thicker plates to give a higher tensile stress but maintain the same characteristics. This would save weight and the sixth column of Table III shows the amount that could be saved by re-designing to the same stress as the equivalent Asspi section.

Comparison can now be made on level terms, and the last column of Table III shows the comparisons of weight of Asspi with weight of re-designed rectangular plates. It will be seen that increase in both m and n reduce the weight saving until when $m = 6$ (the value adopted in the patent), the Asspi section is actually heavier. It cannot, therefore, really be said that on theoretical grounds the Asspi section is attractive, and the thinner the section the less attractive it becomes.

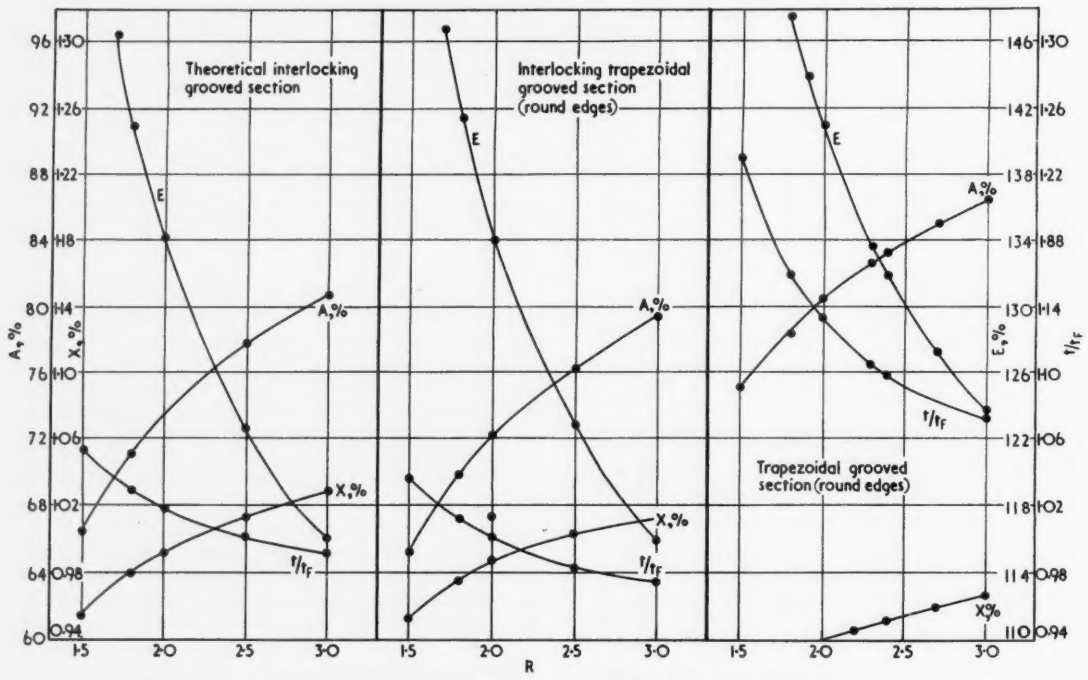


Fig. 7—Characteristics of various sections for values of R

Interlocking characteristics have, however, some attractions and it occurred to the author some years ago to see whether it was possible to combine interlocking characteristics with the single groove section without increasing the tensile stress and still obtaining useful saving in weight. The section evolved is shown diagrammatically in Fig. 6.

It was found too complicated to deal with varying values of m, n, P, and C, and so after some trials of the effect of varying one variable at a time it was realized that the greater the value of m and the smaller the value of n, the greater the efficiency and on the other hand if m was greater than about 10 the lock was weak, and if n was less than 3·5 the depression in the tension face became unduly deep, so the characteristics with $m = 10$ and $n = 3{\cdot}5$ were investigated. Again if P is less than about 2·25 the bridge section seemed to be very thin so this value was adopted.

With other values different characteristics would, of course, be obtained.

It was then found that if $b/c = R$ and y = distance of neutral axis from tension face $= x\overline{Y}$ where $\overline{Y}$ is the distance of the neutral axis from the tension face in the true rectangle :

$$A = \frac{100}{3Ex^2}\ \%\ \text{of equivalent rectangle}$$

where E = efficiency factor of section

$$t/t_F = \frac{315(9R - 5)}{3159R - 2275}$$ where t = section thickness and t_F = thickness of equivalent rectangle

$$E + 1 = \frac{5(9R - 5)(871884R - 651700)}{3(3159R - 2275)^2}$$

$$x^2 = \frac{R(3159R - 2275)}{105E(9R - 5)^2}$$

The right hand side in every case is a function of R and, therefore, each expression can be plotted against R on the same diagram. This is shown in Fig. 7.

It will be seen that with $R = 3$, the figure adopted by the Americans for the single groove section, the tensile stress (curve X) is about 3% higher than in the theoretical rectangle (about the same as a standard concave section) and the saving in weight is about 19% against about 12% for the single groove section, which seemed attractive, and as C increases (i.e. R smaller) both the tensile stress and weight are reduced until, when $R = 1{\cdot}9$, the stress is the same as the theoretical rectangle and the saving in weight is about 27½%, which seems very attractive.

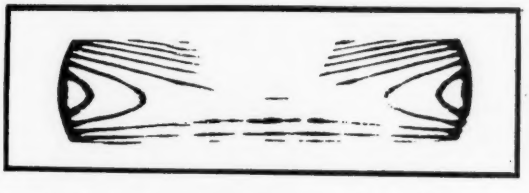


Fig. 8—Photo-elastic representation of standard trapezoidal section

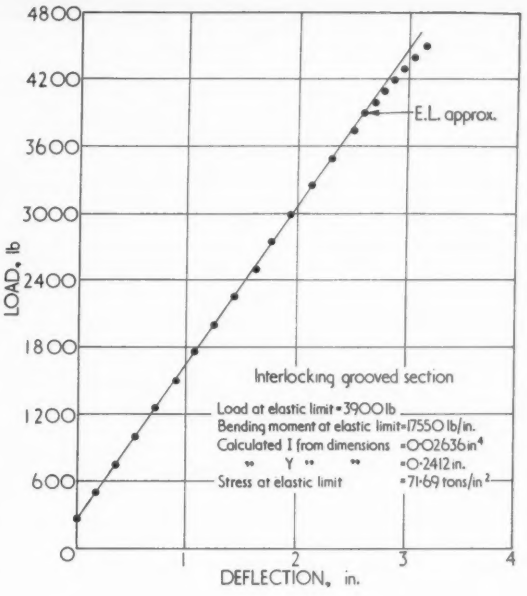


Fig. 9—Theoretical calculation of load deflection in interlocking grooved section

This chart was, of course, for a theoretical and not a practical section. It was, therefore, decided to make the groove trapezoidal and round the edges similarly to the trapezoidal grooved section and to construct a similar diagram for the trapezoidal grooved section with varying values of R and the same bridge thickness as for the interlocking section. These two charts are also shown in Fig. 7.

It will now be seen that with $C = 1/3b$ (i.e. $R = 3$), as in standard trapezoidal section, the tensile stress is only 1½% above the theoretical rectangle (at least as good as standard concave section), and the weight saved is just over 20%, against 13½% for trapezoidal section.

If, however, $R = 2$, the tensile stress is 1% less than the standard rectangle and the weight saved is 27½% against the trapezoidal section, in which the weight saved is 19½% but the tensile stress is reduced 6%. The figures were roughly confirmed on actual tests.

It is very doubtful whether advantage can be taken of this reduction in tensile stress in the trapezoidal section to achieve a further reduction in weight, so that unless trouble due to stress is being experienced with the original spring from normal plates, the interlocking section seems to have attractions over the trapezoidal section.

Table IV shows calculated comparisons to replace a 2½ in. × $\frac{7}{16}$ in. standard concave section for $R = 2$ from which it will be seen that the reduction in weight is over 25%, against 18% for trapezoidal section, and the reduction in tensile stress 0·81%, against 6·81% for the trapezoidal section. Both sections are lower in tensile stress than the plate replaced and the

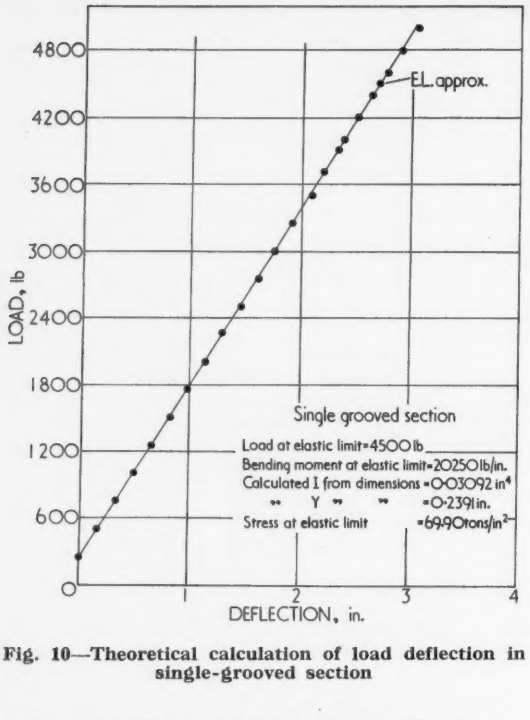


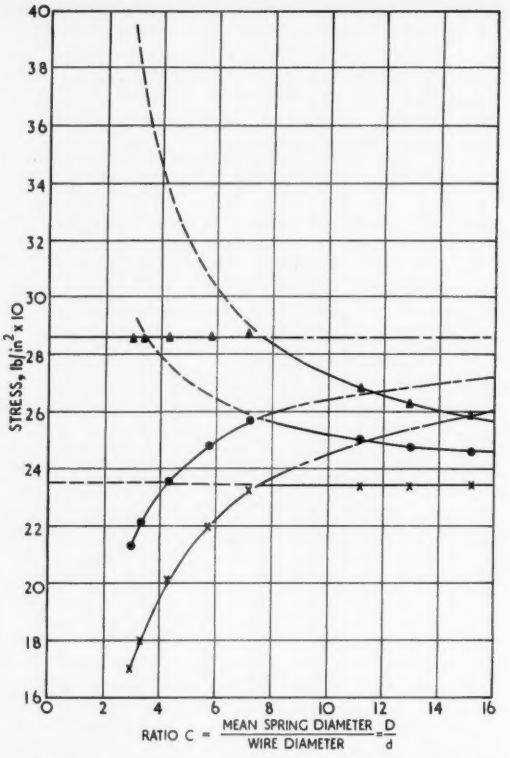
Fig. 10—Theoretical calculation of load deflection in single-grooved section

saving in weight in the interlocking section is considerably greater than in the trapezoidal section.

The question arises as to whether there are any injurious stress concentrations. The Americans have done some photo-elastic work by scattered light on the standard trapezoidal section ($R = 3$), and their illustration is given in Fig. 8, which seems to show no serious stress concentration.

If there are no serious stress concentrations the section may have attractions where saving in weight is important, although the rolls would be expensive and the section difficult to roll. Experimental sections of the dimensions shown in Table IV were made and tested by load/deflection tests and agreed as reasonably as could be hoped with the theoretical calculations as shown in Figs. 9 and 10. Figure 11 shows the three sections discussed.

There is a disadvantage with all three sections in that the compressive stress is increased very greatly. So far as settling is concerned, this can be dealt with by adequate scragging, since the elastic limit can be increased by about 50%, but the question arises what



Patented carbon-steel wire, 0·104 in. dia. Direction of winding during test, to close coils; maximum stress, compressive

● Stress at elastic limit, calculated from measurements

▲ Maximum compressive stress, calculated from ● by multiplying by factor $K_C = 4C/(4C - 3)$

■ Maximum tensile stress, calculated from ● by multiplying by factor $K_T = 4C/(4C + 3)$

—— · —— Deduced from mean ▲ between $C = 3$ and $C = 5{\cdot}75$.

– – – – – Deduced from mean ■ between $C = 11{\cdot}2$ and $C = 15{\cdot}2$.

Fig. 12—Curvature corrections, patented springs

effect the resulting complex stress distribution has on fatigue life.

The lower surfaces of the locks in the interlocking section with $R = 2$ are oscillating between a small tensile stress and a large compressive stress with the mean stress compressive.

Extensive fatigue tests or preferably service life tests are essential before adopting the section. Although it is said that fatigue failures do not occur as a result of oscillating compressive stresses, they

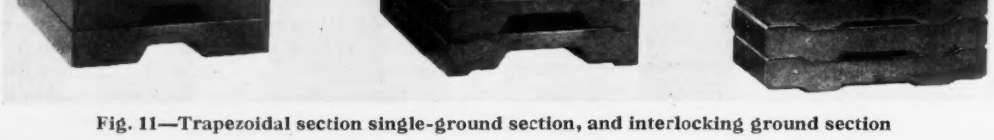


Fig. 11—Trapezoidal section single-ground section, and interlocking ground section

Table V
EFFECT OF WIRE SIZE

Wire Dia., in.	Makers' Specification: Ultimate tensile strength range, tons/in²	Makers' Specification: Average ultimate tensile strength, tons/in²	Tensile Elastic Limit (Intrados): Elastic limit r_1, tons/in²	Tensile Elastic Limit (Intrados): Percentage of average ultimate tensile strength	Tensile Elastic Limit (Extrados): Elastic limit r_2, tons/in²	Tensile Elastic Limit (Extrados): Percentage of average ultimate tensile strength	Compressive Elastic Limit (Intrados): Elastic limit r_3, tons/in²	Compressive Elastic Limit (Intrados): Percentage of average ultimate tensile strength	$\frac{r_2}{r_3}$	Critical, Ratio $\overline{C}$
0·064	132/142	137	111·8	81·58	113·3	82·69	137·2	100·1	1·211	7·859
0·104	122·5/132·5	127·5	104·6	82·04	105·4	82·68	128	100·4	1·214	7·762
0·128	115/125	120	93·43	77·84	94·54	78·77	115·1	95·92	1·217	7·663
0·160	107·5/117·5	112·5	87·70	77·96	88·63	78·77	107·8	95·85	1·217	7·663
0·212	95/105	100	85·01	86·00	86·00	104·9	104·9	104·9	1·220	7·568
		Averages		80·85		81·78		99·43		7·703

are not impossible with oscillation between small tensile and large compressive stresses.

All these sections are expensive and at the best only save about 28% of weight. To save this amount of weight in the ordinary conventional plate would mean allowing an increase of 14% on the maximum tensile stress, which seems likely to be practicable by shot peening.

Fascinating though these special sections are, there are probably safer and cheaper ways of saving at least as much weight and probably more. There is also the question of the effect of the superimposed stresses due to the wind-up caused by starting and braking torques to be considered. This may prove to be a limiting feature with the interlocking grooved section, but only very extensive service experience can decide the significance of this point.

HELICAL TORSION SPRINGS

The author has recently published a paper[6] on small helical torsion springs from round patented wire, of which the following is a summary.

A very large number of torque/deflection tests were carried out on small helical torsion springs from round wire.

The theoretical curvature corrections work out as:

$$K_i = \frac{4C}{4C-3} \text{ for round wire or}$$

$$\frac{3C}{3C-2} \text{ for rectangular wire}$$

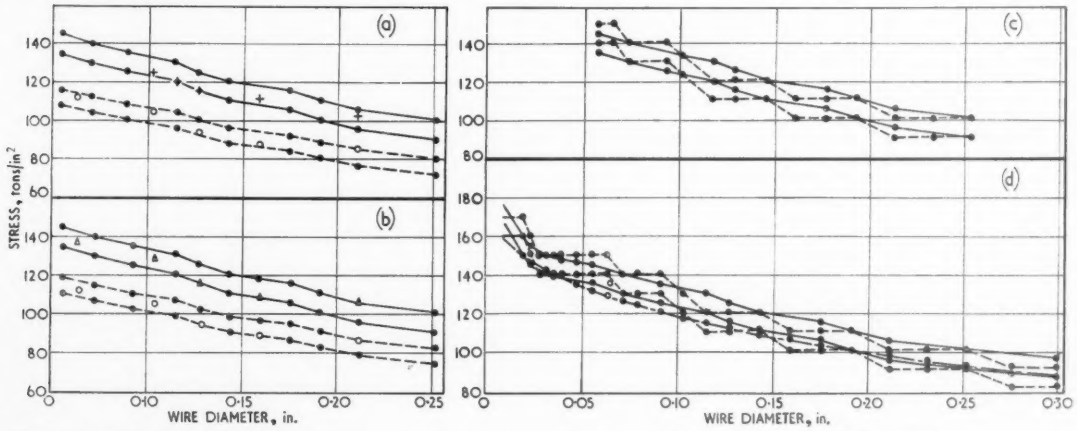
where K_i is the correction for stress at the intrados and C is D/d or D/t, where d is wire diameter, t is radial thickness of rectangular section, and D is mean spring diameter;

$$K_0 = \frac{4C}{4C+3} \text{ for round wire or}$$

$$\frac{3C}{3C+2} \text{ for rectangular wire}$$

where K_0 is the correction factor for stress at the extrados.

A correction for the deflection formula was also determined theoretically but was so small that it can



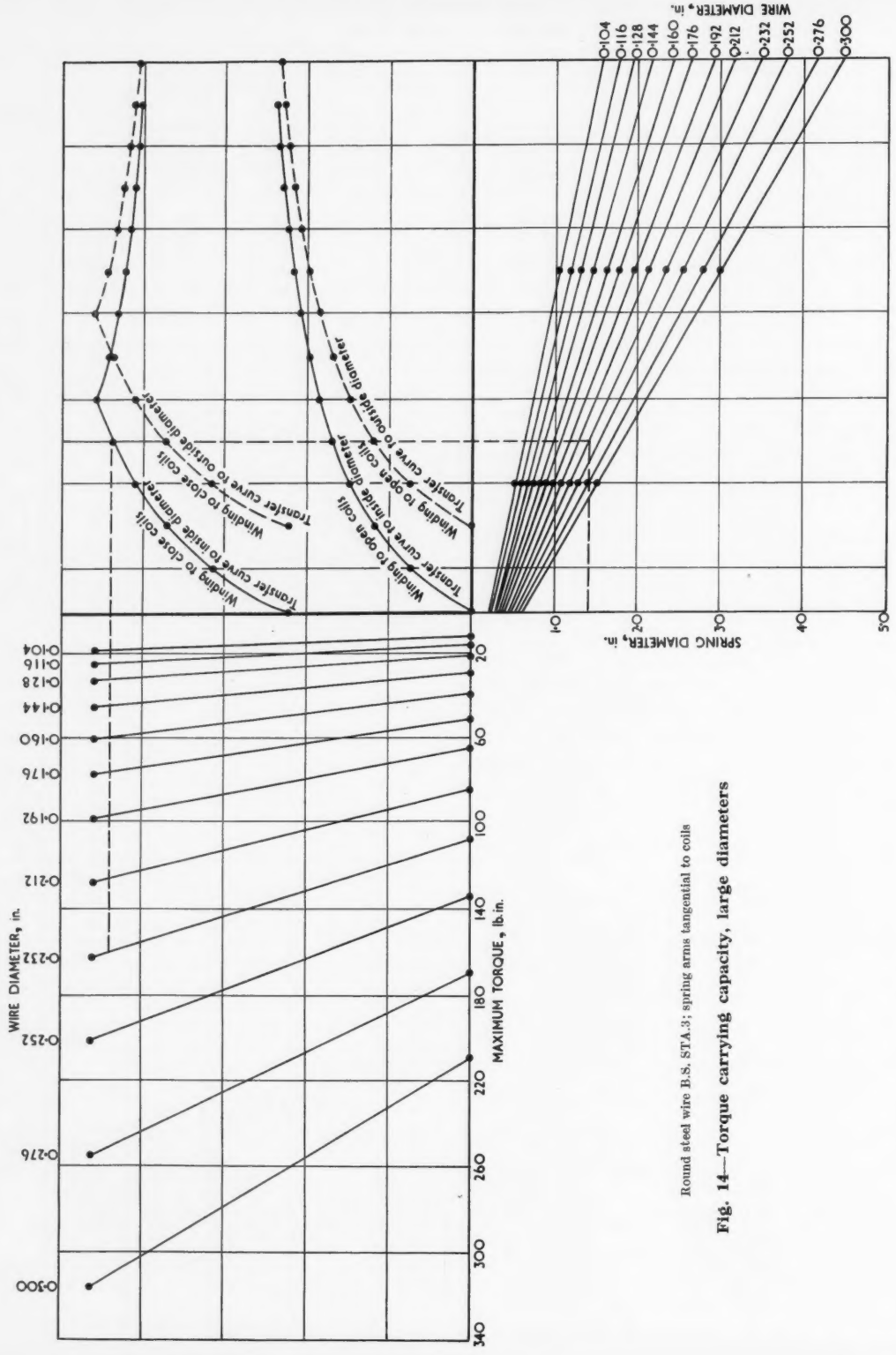
a Test results compared with maker's figures
- ——— Maker's specified T.S. range
- — — — 80% of T.S. range
- \+ Check tests on actual wire
- ○ Elastic limit in tension at intrados

b Test results compared with maker's figures
- ——— 100% of maker's specified T.S. range
- — — — 82% of T.S. range
- Δ Elastic limit in compression at intrados
- ○ Elastic limit in tension at extrados

c Maker's figures compared with B.S. STA.3
- ——— Maker's specified T.S. range
- — — — B.S. STA.3 T.S. range

d Maker's specification and B.S. STA.3 compared with values for T.S. = $195(1 - 0{\cdot}853\sqrt[3]{d})$
- ——— Patented wire
- — — — STA.3
- — - — - T.S. = $195/1 - 0{\cdot}85\sqrt[3]{d}$)

Fig. 13—Comparative test results, effect of wire size



Round steel wire B.S. STA.3; spring arms tangential to coils

Fig. 14—Torque carrying capacity, large diameters

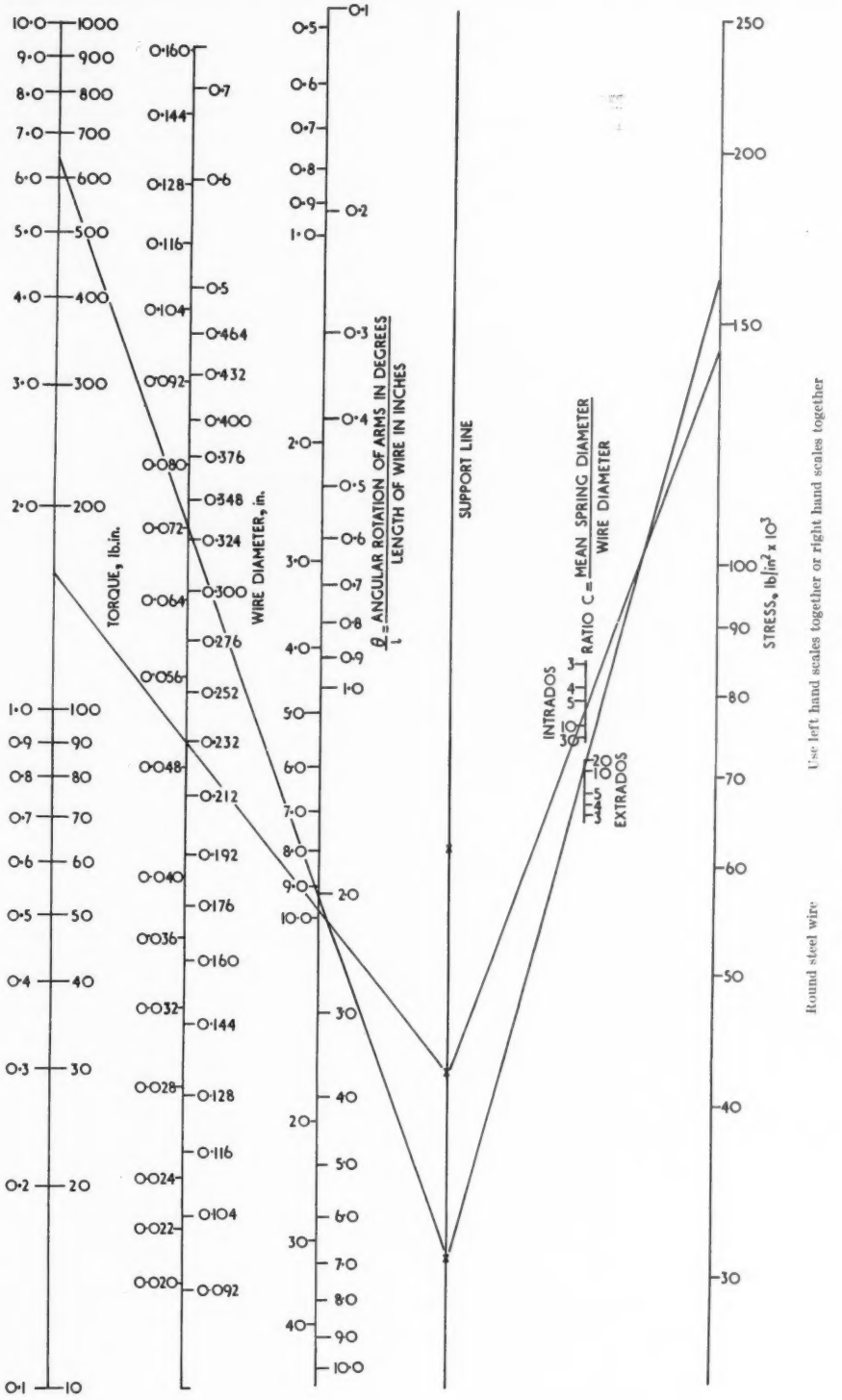

TORQUE, lb.in.
WIRE DIAMETER, in.
θ/l = ANGULAR ROTATION OF ARMS IN DEGREES / LENGTH OF WIRE IN INCHES
SUPPORT LINE
RATIO C = MEAN SPRING DIAMETER / WIRE DIAMETER
INTRADOS
EXTRADOS
STRESS, lb/in² x 10³
Round steel wire
Use left hand scales together or right hand scales together

Fig. 15—Nomogram, angular rotation under torque

be neglected as errors of measurement are liable to swamp it. As a matter of interest it is:

$$K_D = \frac{4C^2 - 1}{4C^2} \text{ for round wire or}$$

$$\frac{15C^2 - 4}{15C^2} \text{ for rectangular wire.}$$

Attempts to check the stress corrections disclosed an unexpected phenomenon. If the direction of winding tends to close the coils, the stress on the intrados is compressive and similarly if the direction of winding tends to open the coils the stress on the intrados is tensile. Applying the curvature correction to the stress at the elastic limit should give a horizontal straight line for the stress at the intrados, since this is the maximum stress.

Testing springs fully heat-treated after coiling did, in fact, result in straight horizontal lines for all values of C when corrected by the curvature correction K_i. Similarly, with patented wire a horizontal straight line was obtained irrespective of C, after correction, when the coils tended to open, i.e. at maximum stress tensile.

When, however, the coils tended to close with springs made from patented wire, unexpected results were obtained; and it eventually became evident that what was happening was as shown in Fig. 12.

At low values of C the springs behaved normally and yielded in compression but, rather surprisingly, at considerably higher values than those obtained at maximum stress tensile. At larger values of C, however, the springs did not yield due to the maximum compressive stress on the intrados but due to the lower tensile stress on the extrados. The change is at about $C = 7{\cdot}5$.

This phenomenon can be utilized in patented wire springs; the operation of closing the coils can be designed for higher stresses than the operation of opening them, provided that the arms are tangential to the coils.

It will be seen that when the operation is to close coils, i.e. maximum stress compressive, there is a critical ratio at which the yielding changes from the intrados to the extrados; and this appears to be independent of wire size, as shown in Table V.

The wire manufacturers acceptance test range of U.T.S. figures was obtained and compared with S.T.A. 3 as shown at c and d in Fig. 13.

On Fig. 13d has been plotted an empirical curve of the expression

$$\text{U.T.S.} = 195\ (1 - 0{\cdot}85\ \sqrt[6]{d})$$

which seems to fit these curves reasonably.

Values derived from this curve can be used as the elastic limit for maximum stress compressive below critical ratio, with the intrados correction; 82% of the values derived from the curve as the elastic limit when maximum stress is compressive above the critical ratio, with extrados correction; and 80% of the values derived from the same curve as the elastic limit when maximum stress is tensile, with the intrados correction.

For design purposes a factor of safety should be used and, judging by experience with tension and compression springs, for most purposes a factor of 70% of the elastic limit seems to be reasonable. We can thus prepare design charts incorporating 70% of the elastic limit of the wire under all conditions and the critical ratio.

Charts for the useful range of S.T.A.3 are given in the original paper and one of them is shown in Fig. 14.

Finally, the deflection can be determined from the line chart shown in Fig. 15 and the stress checked on the same chart.

A word of warning is, however, necessary. If the arms of the spring are not tangential, the radius where the arms join the coils may become the dominant feature and force the use of the chart for the condition of the coils opening even though the coils themselves may actually close. It behoves designers, therefore, to be most careful in the design of the arms of helical torsion springs particularly if they will be made from patented wire.

Acknowledgment

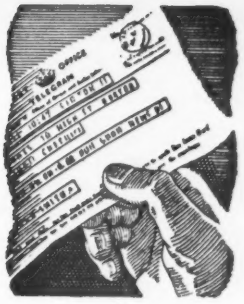
The author wishes to thank Capt. A. Kyle, Chairman of Jonas Woodhead and Sons, Ltd., for permission to publish the results of work done on the interlocking grooved section while employed there, and the Editor of *Mechanical World* for permission to reprint Fig. 2. Other sources of information quoted in the paper are acknowledged in the text.

References

1. J. A. Haringx: *Philips Res. Rep.*, 1948, vol. 3, pp. 401–409.
2. " Design of Helical Compression Springs ": Ministry of Supply Design Data Sheets, H.M.S.O.
3. B. Mackenzie: *Inst. Mech. E. Automobile Division Proc.*, 1947/48, p. 122.
4. S. Timoshenko: " Strength of Materials," Part II, p. 479: 1936, London.
5. A. M. Wahl: " Mechanical Springs," First ed.: 1944, Cleveland, Ohio.
6. W. R. Berry: *Proc. Inst. Mech. Eng.*, 1953, vol. 167, No. 4, ser. *A*, pp. 375–393.

N E W S

Announcements and News of Science and Industry



IRON AND STEEL INSTITUTE

President-Elect

At the Autumn General Meeting the President, Sir Charles Bruce-Gardner, Bt., announced that the Council had decided unanimously to nominate Dr. H. H. Burton, C.B.E. (English Steel Corporation Ltd.), a Vice-President, for election as President, to take office for one year at the Annual General Meeting in 1956.

Annual General Meeting, 1956

As previously announced, the Annual General Meeting will be held in London on Wednesday and Thursday, 16th and 17th May, 1956. The dinner for Members will be held at Grosvenor House on the evening of 16th May.

Bessemer Centenary

In connection with the Meeting Mr. James Mitchell, C.B.E. (Past-President) has agreed to give a lecture to commemorate the centenary of the Bessemer Process. This will probably be delivered on the evening of the day before the Meeting, i.e. on Tuesday, 15th May.

Hatfield Memorial Lecture

Professor N. F. Mott, F.R.S., Cavendish Professor of Experimental Physics, University of Cambridge, has agreed to giving the Ninth Hatfield Memorial Lecture on "Fracture in Metals." This will probably be delivered during the Opening Session of the Annual General Meeting on Wednesday, 16th May, 1956.

Special Meeting in France

As previously announced, the Council has accepted invitations from the Chambre Syndicale de la Sidérurgie Française and the Société Française de Métallurgie to hold a Special Meeting in France in June, 1956. The dates are as follows:

Main Meeting in Paris from the afternoon of Tuesday, 5th June to Sunday, 10th June. During this period there will be technical sessions for the discussion of British and French papers, visits to works and laboratories, and social functions. A full day's excursion to the works of the Sté. Métallurgique de Normandie at Mondeville, near Caen, will also be arranged.

Following the Meeting in Paris visits will be paid to iron and steelworks in Northern France (Lille, Valenciennes, Denain), to Lorraine, and to Le Creusot and St. Etienne. These will last three or four days. A programme is being arranged for the Ladies and details will be announced later.

Joint Metallurgical Societies Meeting in Europe Additional Presentations in France

The following presentations, which were made during the Meeting in Paris, are additional to those listed in the December, 1955, issue of the *Journal* (pp. 289–290).

Dr. George Roberts, President of the American Society for Metals, and Dr. Ernest O. Kirkendall, Secretary of the American Institute of Mining and Metallurgical Engineers, presented Honorary Life Memberships in the Society and Institute to Monsieur Raoul de Vitry and Dr. Eugène Dupuy, President and General Secretary of the Société Française de Métallurgie.

Sheffield University—Iron and Steel Institute Prize

The Iron and Steel Institute Prize for 1955 has been awarded to Mr. D. J. Street, who has gained the degree of B.Met. with honours, on the results of examinations taken in June, 1955. Mr. Street receives £10.

NEWS OF MEMBERS

Mr. **J. E. Aisbitt** has taken up a post at the Openshaw Works of the English Steel Corporation Ltd.

Dr. **P. J. Allender** has taken up an appointment with the Research Laboratory of the British Thomson-Houston Co., Ltd., Rugby.

Mr. **L. E. Benson** has been awarded the degree of D.Sc. in the University of Manchester.

Mr. **H. Blegen** has been appointed Managing Director of the Electric Furnace Products Co., Ltd., Sauda, Norway.

Mr. **E. J. Bradbury** has been appointed Assistant Superintendent of the Development and Research Department Laboratory of the Mond Nickel Co., Ltd., Birmingham.

Mr. **R. J. Brown** has been appointed Materials Engineer with the Austin Motor Co., Ltd., Longbridge, Birmingham.

Mr. **W. J. Brown** has left the Wellman Smith Owen Engineering Corporation Ltd., to become Sales Representative for the Goyt Bank Engineering Co., Ltd., and the Elevating and Conveying Equipment Department of Westwood, Dawes and Co., Ltd.

Mr. **M. C. Caplan** has taken up an appointment with the General Electric Co., Ltd., Erith, Kent.

Dr. **C. J. Dadswell** has been appointed a Director of the English Steel Corporation Ltd.

Dr. **D. W. Davison** has returned from Australia and has joined the Chemical and Metallurgical Division of the Plessey Co., Ltd., Towcester, Northants.

Mr. **M. Deighton** has been awarded the degree of B.Sc. (Hons.) in the University of Durham.

Mr. **B. J. Duckfield** has been appointed Investigator with the British Non-ferrous Metals Research Association.

Mr. **E. G. Eeles** has left the Department of Physical Metallurgy of the University of Birmingham and he has received a post-doctorate Fellowship with the Low-temperature and Solid-state Physics Group of the National Research Council, Ottawa.

Mr. **P. L. Fairfield** has taken up the appointment of Engineer-in-Charge, Hydraulic Engineering Department of the Harland Engineering Co., Ltd., Alloa.

Mr. **B. France** has taken up a post as Metallurgist with MacDonald Brothers (Aircraft) Ltd., Winnipeg.

Dr. **R. H. Hickley,** formerly of the Mond Nickel Co., Ltd., has been appointed as Metallurgist in charge of

Research and Development with John M. Moorwood Ltd., Sheffield.

Mr. **J. G. Hines** has been appointed Technical Officer in the Billingham Division of Imperial Chemical Industries, Ltd.

Dr. **D. E. R. Hughes** has taken up the position of Metallurgist to the Operations Branch of the Industrial Group, U.K. Atomic Energy Authority, Risley, Warrington.

Mr. **R. S. Jackson** has been appointed Works Metallurgist with Deloro Stellite Ltd., Birmingham.

Mr. **S. Kay** has been appointed Chairman and Managing Director of the Cooper Roller Bearing Co., Ltd.,

Mr. **F. A. Klouman** has been appointed Director and Deputy Chairman of J. Blakeborough and Sons Ltd., Brighouse, Yorkshire.

Mr. **A. K. Lahiri** has been appointed Senior Scientific Assistant at the National Metallurgical Laboratory, Jamshedpur.

Mr. **A. G. MacKenzie** has left the Research and Technical Development Department of Stewarts and Lloyds Ltd. to become Assistant Manager of the Open-hearth Plant at Corby.

Mr. **H. L. Morgan** has taken up an appointment of Foundry Metallurgist with the Westinghouse Brake and Signal Co., Ltd., Chippenham.

Mr. **V. Pendred** has been appointed Managing Director of the newly formed Head Wrightson Export Co., London, S.W.1.

Mr. **J. W. Pokorny** has resigned from the British Thomson-Houston Co., Ltd., and has joined the Research Laboratory, Metals Division, of Imperial Chemical Industries Ltd., Witton, Birmingham.

Mr. **L. Pryce** has been elected a Fellow of the Institution of Metallurgists. He has also left the Metallurgical Section of the Research and Development Department of The United Steel Companies Ltd., Rotherham, to join the Research Staff of S. Fox and Co., Ltd., Stocksbridge.

Mr. **W. D. Pugh** has relinquished the office of Managing Director of the Darlington Forge Co. Ltd., and has been appointed Deputy Chairman.

Mr. **J. A. Robinson** has been awarded the degree of B.Sc. (Hons. Met.) in the University of Durham and has been appointed Junior Research Metallurgist with the Metropolitan-Vickers Electrical Co., Ltd., Manchester.

Dr. **K. Sachs** has been appointed Research Metallurgist with the G.K.N. Group Research Laboratories, Wolverhampton.

Mr. **F. Sharp** has been appointed Director of John Sharp (Wire) Ltd., Cleckheaton, Yorkshire.

Mr. **I. Walker** has been appointed Head of Laboratory of Briggs Motor Bodies Ltd.

Mr. **D. H. Wilkinson** has taken up an appointment with the Cerro de Pasco Corporation, Las Oroya, Peru.

Obituary

Mr. **Heber von Lauer** of Gary, Indiana.

Mr. **J. Nightingale** of the Workington Iron and Steel Co., on 5th November, 1955.

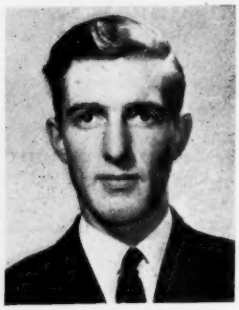
CONTRIBUTORS TO THE JOURNAL

Dr. **W. R. Berry**—Consulting Engineer and Metallurgist.

Dr. Berry was educated at Manchester Grammar School, and Victoria University, Manchester, and obtained the degrees of B.Sc. in 1918 and M.Sc. in 1920. He obtained the degree of Ph.D. from the Leeds University in 1950.

During the 1914–18 war Dr. Berry served as Chemist

W. R. Berry



G. W. Horsley

on the staff of the Deputy Inspector of High Explosives, joining H.M. Forces in the last year of the war. He served for a short period in 1920 as Research Metallurgist at Kynoch Ltd., and from October, 1920 to February, 1943 at the Metropolitan Vickers Electrical Co., Ltd., ultimately becoming Heat Treatment Engineer, being responsible for the design and manufacture of coil springs.

In 1943 Dr. Berry joined Jonas Woodhead and Sons, Ltd., as Chief Engineer, and in 1944 became Chief Development Engineer for the Woodhead Group of Companies, becoming Director of Ibbotson Bros., Ltd., at the end of that year. He resigned in June, 1947 to take up his present occupation.

Dr. Berry is a Member of the Institution of Mechanical Engineers, a Fellow of the Royal Institute of Chemistry, and a Fellow of the Institution of Metallurgists.

Geoffrey W. Horsley, M.A.—Scientific Officer in the Metallurgy Division of the Atomic Energy Research Establishment, Harwell.

Mr. Horsley was educated at Oundle School and at Cambridge University, where he graduated in 1947. He served in the Royal Navy from 1947 until 1951 and then took up his present post at Harwell.

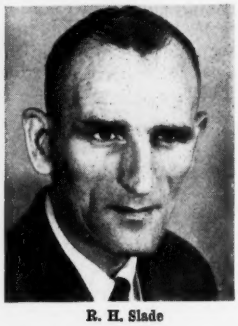
Constantine J. Livadefs—Head of Electrical Engineering Control, Athens Piraeus Electricity Company.

Dr. Livadefs graduated in Mechanical and Electrical Engineering from the National Technical University of Athens in 1928. He was awarded the degree of Doctor of Engineering (Mechanical) in 1944, and that of D.Sc. in 1945. He was connected with the University from 1930 until 1949, first as Instructor, then as Lecturer, and finally as Assistant Professor in Applied Mechanics and Testing of Materials. He joined the Meter Department of the Athens Piraeus Electricity Company in 1928, and took up his present appointment in 1948.

R. H. Slade—Assistant Manager, Slabbing Mill, Steel Company of Wales Ltd., Abbey Works.

Mr. Slade was educated at the Port Talbot Secondary

C. J. Livadefs



R. H. Slade

C. S. Ball

H. P. Tardif

Grammar School before joining the staff of G. K. Baldwins Ltd., at their old Port Talbot Works.

In 1946 he was promoted to Shift Foreman, and in 1950 he was appointed Senior Day Foreman at the Slabbing Mill of the New Abbey Works, where he played a large part in the starting up of the new Mill. Mr. Slade was appointed to his present position in 1953.

C. S. Ball, B. Met., Ph.D., A.I.M.—Assistant Chief Metallurgist with the Steel Division of the Steel Company of Wales Ltd.

Dr. Ball graduated from Sheffield University with the degree of B.Met. in 1944 and joined K. and L. Steelfounders and Engineers; in 1945 he returned to the Faculty of Metallurgy at Sheffield University as a Research Student. The next five years were spent in research into the properties of spring steels on behalf of the Coil Spring Federation, during which time he was awarded his doctorate. In 1950 he was appointed Lecturer in the Department of Industrial Metallurgy at Birmingham University and was concerned with the mechanical working of metals. Dr. Ball took up his present appointment in 1954.

H. P. Tardif, B.A.Sc., M.Sc., Ph.D.—Physical Metallurgist in the Canadian Army Research and Development Establishment.

Dr. Tardif was educated at the Académie de Quebec and the Université de Laval, graduating with honours as B.A.Sc. In 1950 he obtained the M.Sc. degree of the Carnegie Institute of Technology and, after a short period with the Canadian Bureau of Mines, he was awarded an Athlone Fellowship which he elected to spend in the Department of Industrial Metallurgy at Birmingham University. In 1954 he was awarded the degree of Ph.D. from the University for his work on strain-ageing.

AFFILIATED LOCAL SOCIETIES

Manchester Metallurgical Society

The list of Officers for the Session 1955–56 is as follows:

President
C. J. Bushrod, M.Sc.

Vice-Presidents
G. A. Cottell, M.Sc. J. Y. Davies, B.Sc.
K. M. Entwistle, M.Sc., Ph.D.

Hon. Secretary E. Holland, B.Sc.
Hon. Treasurer N. Youatt

Council

W. Ashelby	W. L. Harper, B.Sc.
A. B. Ashton, M.Sc.	F. G. Haynes, M.Eng.
C. F. Brereton	W. A. Jenks
T. W. Collier	W. Sorby, B.Met.
E. F. Emley, Ph.D.	R. H. Wallace

Staffordshire Iron and Steel Institute

The following Officers and Committee have been appointed for the Session 1955–56:

President
K. G. Lewis, M.Sc.

Vice-Presidents
A. Biddulph G. Parkin

Hon. Secretary H. J. E. Jones
Hon. Treasurer G. E. Lunt

Council

W. Angus	M. R. Liddiatt
J. A. Davies	J. Mitton
G. T. Hampton	B. V. Peters
A. Howard	N. F. Truman
R. B. Lane	W. H. Wesson
L. W. Law	F. V. Wright

Council *(ex-officio)*

G. R. Bashforth	A. W. Shore
G. B. Morrison	K. H. Wright

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Ninth Chemists' Conference

Over 160 representatives from firms and organizations within and connected with the iron and steel industry were present at the Ninth Chemists' Conference which was held at Swanwick in Derbyshire on 11th and 12th October, 1955. The chair was taken by Mr. B. Bagshawe. As in previous years, two of the sessions were devoted to analytical techniques, and the third to a topic linking the chemist and the steelmaker. The speakers and their subjects were: Mr. H. A. Sloman (National Physical Laboratory) on "*The determination of nitrogen in iron and steel*"; Mr. R. H. A. Crawley (British Thomson-Houston Co., Ltd.) on "*The analysis of silicon iron*"; Mr. B. Bagshawe (Brown-Firth Research Laboratories) on "*The gravimetric determination of sulphur*"; Mr. L. E. Gardner (Edgar Allen and Co., Ltd.) on "*The absorptiometric determination of copper*"; and Mr. W. S. Sykes (Steel, Peech and Tozer) on "*Some experiences with the A.R.L. Quantometer.*"

NEWS OF SCIENCE AND INDUSTRY

Firth Scholarship

Thomas Firth and John Brown Ltd. are to provide £1300 a year for seven years to augment the endowment of the Firth Scholarship at the University of Sheffield. The value of the Scholarship will be £120 per annum.

Awards for Essays and Papers on Corrosion Science

The Education Panel of the Corrosion Group of the Society of Chemical Industry, with the approval of the Council, announces the establishment of a competition designed to encourage those who are still in the early stages of their career to take an interest in corrosion science and to express their ideas in writing.

Details may be obtained from:

Corrosion Group Essay Competition, c/o Society of Chemical Industry, 56 Victoria Street, London, S.W.1.

Nimonic Alloys

Design data on the entire range of Nimonic alloys, including preliminary details of the recently introduced creep-resisting material Nimonic 100, are contained in a new edition of "*The Nimonic Alloys*," available from Henry Wiggin and Co., Ltd.

Society of Chemical Industry 75th Annual Meeting

"Achievements of Industrial Chemistry" is to be the theme of the 75th Annual Meeting of the Society of Chemical Industry in London in 1956. Speakers will review the major advances brought about by industrial chemists in the last 25 years and will look forward over the next quarter-century to the Society's centenary.

Changes of Name and Address

The general office of AMERICAN STEEL FOUNDRIES will in future be at Prudential Plaza, Chicago 1, Illinois.

The Research Laboratories of THE A.P.V. COMPANY LTD., have removed to Manor Royal, Crawley, Sussex.

The BROCKWORTH ENGINEERING CO., LTD., will in future be known as ARMSTRONG SIDDELEY (BROCKWORTH) LTD.

The London office of THE LOEWY ENGINEERING CO. LTD. has removed to 1 Albemarle Street, W.1.

The Manchester office of THE UNITED STEEL COMPANIES LTD., has removed to National Building, St. Mary's Parsonage, Manchester, 3. Telephone: Blackfriars 3526.

DIARY

5th Jan.—LEEDS METALLURGICAL SOCIETY—"*The Production of Pure Metals*," by J. W. Chaston—Large Chemistry Lecture Theatre, University of Leeds, 7.15 P.M.

9th Jan.—CLEVELAND INSTITUTION OF ENGINEERS—"*American Blast furnaces*," by A. T. Ledgard and A. Embleton—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 P.M.

9th Jan.—LINCOLNSHIRE IRON AND STEEL INSTITUTE—Paper by Herbert Boos (Eisenwerke Gelsenkirchen)—North Lindsey Technical College, Kingsway, Scunthorpe.

10th Jan.—THE INSTITUTION OF ENGINEERING INSPECTION (LEEDS BRANCH)—"*Photoelasticity*," by Dr. J. Ward—Theological Library, Leeds Church Institute, Albion Place, Leeds, 1, 7.30 P.M.

10th Jan.—SHEFFIELD METALLURGICAL ASSOCIATION—"*The Use of Statistical Design in Chemical Analysis*," by G. A. Coutie—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 7.0 P.M.

10th Jan.—SHEFFIELD METALLURGICAL ASSOCIATION—Annual General Meeting of the Methods of Analysis Group, at B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 6.30 P.M.

12th Jan.—LIVERPOOL METALLURGICAL SOCIETY—Open discussion on "*Modern Techniques of Metallurgical Analysis*"—The Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7.0 P.M.

13th Jan.—THE INSTITUTE OF PHYSICS (NON-DESTRUCTIVE TESTING GROUP)—Symposium "*The Possible Uses of Surface Methods as a Means of Testing Metals*" (with special reference to optical methods), led by Professor Tolansky, Dr. R. W. B. Stephens, and Dr. O. S. Heavens—47 Belgrave Square, London, S.W.1, 6.30 P.M.

13th Jan.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Notes on Basic Open-Hearth Melting Shop Practice*," by J. Gibson.

13th Jan.—NORTH EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS—"*Steel for Shipbuilding*," by T. F. Pearson—Mining Institute, Newcastle-upon-Tyne, 6.15 P.M.

16th Jan.—SHEFFIELD SOCIETY OF ENGINEERS AND METALLURGISTS—Presidential Address—The University Building, St. George's Square, Sheffield, 7.30 P.M.

16th Jan.—THE INSTITUTION OF PRODUCTION ENGINEERS (SHEFFIELD GRADUATE SECTION)—"*Heat Treatment*" — English Steel Corporation Ltd., Sheffield, 9.

16th Jan.—EAST MIDLANDS METALLURGICAL SOCIETY—"*Weather Forecasting*," by A. E. Mayers—Nottingham and District Technical College, Shakespeare Street, Nottingham, 7.30 P.M.

17th Jan.—SHEFFIELD METALLURGICAL ASSOCIATION—Annual General Meeting of the Refractories Group. "*Electric Arc Furnaces—Hearths*," by P. F. Young—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 7.0 P.M.

17th Jan.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY—General Meeting. "*Modern Blast-furnace Practice*," by K. C. Sharpe—Central Library, Swansea, 7.0 P.M.

17th Jan.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY—Industrial Film Show—Whitehead Institute, Cardiff Road, Newport, 7.0 P.M.

18th Jan.—MANCHESTER METALLURGICAL SOCIETY—"*Applications of Ultrasonics in Metallurgy*," by P. D. Southgate—Lecture Room, Central Library, Manchester, 6.30 P.M.

18th Jan.—NORTH WALES METALLURGICAL SOCIETY—"*Recent Developments in Aluminium and Aluminium Alloys*," by P. C. Varley—County Primary School, Plymouth Street, Shotton, Nr. Chester, 7.15 P.M.

19th Jan.—NORTH EAST METALLURGICAL SOCIETY—"*60 Years of Non-destructive Testing*," by J. F. Hinsley, Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 P.M.

19th Jan.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Film Evening—7.30 P.M.

24th Jan.—CLEVELAND SCIENTIFIC AND TECHNICAL INSTITUTION—"*Mechanical Handling of Material*," by F. T. Dean—Darlington, 7.0 P.M.

24th Jan.—SHEFFIELD METALLURGICAL ASSOCIATION—Annual General Meeting and Address by the New President—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 7.0 P.M.

25th Jan.—THE INSTITUTION OF ENGINEERING INSPECTION (WEST OF SCOTLAND BRANCH)—"*Use of Electro Deposits and Ancillary Processes in the Protection of Metals*," by S. A. J. Murray—St. Enoch Hotel, Glasgow, 7.30 P.M.

25th Jan.—CHEMICAL ENGINEERING GROUP—"*Control of Corrosion in the Heavy Chemical Industry*," by D. R. Himsworth and W. D. Clark (Joint meeting with Corrosion Group and The Institution of Chemical Engineers)—Large Lecture Theatre, King's College, London, 6.30 P.M.

26th Jan.—THE INSTITUTE OF FUEL (EAST MIDLAND SECTION)—"*Recent Developments in Fuel Technology*," by A. L. Roberts—Gas Showrooms Lecture Theatre, Nottingham, 6.15 P.M.

31st Jan.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Inspection and Testing of High Quality Steel Castings*," by J. Johnson.—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3, 7.0 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the October, 1955, issue of the *Journal*, p. 172.)

TRANSLATION IN COURSE OF PREPARATION

(German). H. POHL: "Sizing of Lump Ores." (*Stahl u. Eisen*, 1955, vol. 75, Oct. 6, pp. 1295–1300).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

CONTENTS

Abbreviations and List of Periodicals	97	Machinery for Iron and Steel Plant	108
Mineral Resources	101	Lubrication	108
Ores—Mining and Treatment	101	Welding and Flame-Cutting	109
Fuel—Preparation, Properties, and Uses	102	Cleaning and Pickling	110
Temperature Measurement and Control	103	Protective Coatings	111
Refractory Materials	103	Powder Metallurgy	112
Blast-Furnace Practice and Production of Pig Iron	103	Properties and Tests	113
		Metallography	115
Treatment and Use of Slags	104	Corrosion	115
Direct Processes	104	Analysis	116
Production of Steel	104	Industrial Uses and Applications	117
Production of Ferro-Alloys	105	Historical	118
Foundry Practice	105	Economics and Statistics	118
Reheating Furnaces and Soaking Pits	106	Miscellaneous	118
Heat-Treatment and Heat-Treatment Furnaces	106	Book Notices	119
Forging, Stamping, Drawing, and Pressing	106	New Publications	120
Rolling-Mill Practice	107		

ABBREVIATIONS AND LIST OF PERIODICALS EXAMINED BY THE ABSTRACTING SERVICE

Abhandlungen der **Braunschweig**ischen **wiss**enschaftlichen **Ges**ellschaft (Brunswick)
Acciaio e **Costruzioni Met**alliche (Milan)
Acciaio Inossidabile (Milan)
Acero y **Energ**ia (Barcelona)
Acier Stahl Steel (Brussels)
Aciers Fins et **Spéc**iaux **Franç**ais (Paris)
Acta Crystallographica (London)
Acta Metallurgica (Toronto)
Acta Physica Polonica (Warsaw)
Acta Polytechnica (Stockholm)
Acta Technica (Budapest)
Advancement of **Sc**ience (London)
Advances in **Phys**ics (London)
Aeroplane (London)
Aircraft Engineering (London)
Aircraft Production (London)
Alloy Castings **Bull**etin (New York)
Alloy Metals Review (Widnes)
Alluminio (Milan)
Aluminium (Düsseldorf)
Aluminium Development **Assoc**iation, **Inform**ation **Bull**etin (London)
American **Foundr**ymen's **Soc**iety, **Pre-print** (Chicago)
American **Inst**itute of **Min**ing and **Met**allurgical **Eng**ineers (New York)
Blast Furnace, **Coke Oven** & **Raw Mat**erials **Comm**ittee, **Proc**eedings
Electric **Furn**ace **Steel Conf**erence **Proc**eedings
Proceedings **Nat**ional **Open-Hearth Comm**ittee
Proceedings **Symposia Series**
American **Iron** and **Steel Inst**itute (New York)
Annual Statistical Report
Contributions to the **Met**allurgy of **Steel**
Steel Products Manual
American **J**ournal of **Phys**ics (New York)
American **J**ournal of **Sc**ience (New Haven, Conn.)
American **Soc**iety for **Metals, Preprint** (Cleveland, Ohio)
American **Soc**iety for **Test**ing **Mat**erials (Philadelphia)
Preprint
Special Technical **Publ**ication
Anais da **Acad**emia **Brasil**eira de **Cienc**ias (Rio de Janeiro)
Anais Associacao Brasileira de **Quim**ica (Sao Paulo)
Anales de la **Asociacion Quim**ica **Argentina** (Buenos Aires)
Anales de la Real Sociedad Española de **Fis**ica y **Quím**ica (Madrid)
Anales de **Mec**anica y **Elect**ricidad (Madrid)
Analyst (London)
Analytica Chimica **Acta** (New York and Amsterdam)
Analytical Chemistry (Washington)
Annales des **Mines** (Paris)
Annales de la **Soc**iété **Sc**ientifique de **Bruxelles** (Brussels)
Annual Proceedings of the **Sheet** and **Strip Metal Users' Techn**ical **Assoc**iation (London)
Annual Report of the **Smithsonian Inst**itution (Washington)
Annual Review of **Phys**ical **Chem**istry (Stanford, California)
Anvil (Sheffield)
Applied Mechanics **Rev**iews (New York)
Applied Research **Lab**oratories, **Rep**orts (Glendale, Calif.)
Applied Scientific **Res**earch (The Hague)
Archiv für das **Eisenhüttenwesen** (Düsseldorf)
Archiwum Gornictwa i **Hutnictwa** (Warsaw)
Arkiv för **Fysik** (Stockholm)
Arkiv för **Kemi** (Stockholm)
Arkiv för **Min**eralogi och **Geol**ogi (Stockholm)
Arts et Manufactures (Paris)
Atomics (London)
Atti della **Acc**ademia **Naz**ionale dei **Lincei. Rend**iconti della **Classe** di **Sc**ienze **Fis**iche, **Mat**ematiche e **Nat**urali (Rome)
Australasian Engineer (Sydney)
Australian Journal of **Appl**ied **Sc**ience (Melbourne)
Australian Journal of **Chem**istry (Melbourne)
Australian Journal of **Phys**ics (Melbourne)
Australian Machinery (Sydney)
Automobile Engineer (London)
B.C. Professional Engineer (Vancouver)
B.H.P. Review (Melbourne)
Ball Bearing Journal (Luton)
Battelle Technical **Rev**iew (Columbus, Ohio)
Beama Journal (London)
Bell Laboratories **Record** (New York)
Bell System Technical **J**ournal (New York)

Bell Telephone System Technical Publication (New York)
Bell Telephone Magazine (New York)
Berg- und hüttenmännische Monatshefte (Vienna)
Bibliographical Bulletin of Welding (Paris)
Blad för Bergshandteringens Vänner (Stockholm)
Blast Furnace and Steel Plant (Pittsburgh)
Boletim da Associação Brasileira de Metais (São Paulo)
Boletim da Associação Química do Brasil (Rio de Janeiro)
Boletim da Sociedade Geológica de Portugal (Oporto)
Boletim do INT (Rio de Janeiro)
Boletin Minero e Industrial (Bilbao)
Brennstoff–Warme–Kraft (Dusseldorf)
British Cast Iron Research Association, Journal of Research and Development (Birmingham)
British Coal Utilisation Research Association, Monthly Bulletin (London)
British Coke Research Association, Technical Papers (London)
British Dental Journal (London)
British Electrical and Allied Industries Research Association, Reports (London)
British Engineering (London)
British Iron and Steel Federation, Monthly Statistical Bulletin (London)
British Iron and Steel Research Association, Reports (London)
British Journal of Applied Physics (London)
British Steelmaker (London)
British Welding Journal (London)
Brown-Boveri Review (Baden)
Bulletin de l'Académie Polonaise des Sciences (Warsaw)
Classe Quatrième
Classe Troisième
Bulletin of the American Ceramic Society (Columbus, Ohio)
Bulletin, American Society for Testing Materials (Philadelphia)
Bulletin of the British Scientific Instrument Research Association (London)
Bulletin, British Steel Founders' Association (Sheffield)
Bulletin de Cercle d'Etudes des Métaux (St. Etienne)
Bulletin and Foundry Abstracts of the British Cast Iron Research Association (Birmingham)
Bulletin of the Institute of Metal Finishing (London)
Bulletin of the Institution of Metallurgists (London)
Bulletin of the Institution of Mining and Metallurgy (London)
Bulletin of Ohio State University Engineering Experiment Station (Columbus, O.)
Bulletin of the School of Mines and Metallurgy, University of Missouri (Minneapolis)
Bulletin des Sociétés Chimiques Belges (Brussels)
Bulletin of the University of Wisconsin, Engineering Experiment Station Series

Canada Department of Mines and Technical Surveys, Mines Branch, Research and Special Projects Reports (Ottawa)
Canadian Journal of Chemistry (Ottawa)
Canadian Journal of Physics (Ottawa)
Canadian Journal of Technology (Ottawa)
Canadian Metals (Toronto)
Canadian Mining Journal (Quebec)
Canadian Mining and Metallurgical Bulletin (Montreal)
Calore (Milan)
Castings (Sydney)
Centre de Documentation Sidérurgique, Circulaires d'Informations Techniques (Paris)
Ceramics (Leighton Buzzard)
Chaleur et Industrie (Paris)
Chartered Mechanical Engineer (London)
Chemical Age (London)
Chemical Engineering (New York)
Chemical Engineering and Mining Review (Melbourne)
Chemical and Engineering News (Washington)
Chemical Engineering Progress (New York)
Chemical & Process Engineering (London)
Chemické Listy (Prague)
Chemisch Weekblad (Amsterdam)
Chemist-Analyst (Phillipsburg, N.J.)
Chemistry and Industry (London)
Chimica e Industria (Milan)
Chimie Analytique (Paris)
Chimie et Industrie (Paris)
Chrome Dur (Paris)
Ciencia y Tecnica de la Soldadura (Madrid)
Circular of the National Bureau of Standards (Washington)
Circular of Ohio State University Engineering Experiment Station (Columbus)
Claycraft (London)
Coke and Gas (London)
Coke Review (London)
Collection of Czechoslovak Chemical Communications (Prague)
Colliery Guardian (London)
Colonial Geology and Mineral Resources (London)
Colorado School of Mines, Quarterly (Golden, Colorado)
Commonwealth Engineer (Melbourne)
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences (Paris)
Congrès du Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique (Paris)
Corrosion (Houston, Texas)
Corrosion et Anti-Corrosion (Paris)
Corrosion Prevention and Control (London)
Corrosion Technology (London)
Coventry Engineering Society Journal (Coventry)

Dansk Teknisk Tidsskrift (Copenhagen)
Demag News (Duisburg)
Discussions of the Faraday Society (London)
Documentation Métallurgique (Paris)
Doklady Akademii Nauk S.S.S.R.
Draht (English edition) (Coburg)
Draht (German edition) (Coburg)
Dyna (Barcelona)

E.S.C. News (Sheffield)
Echo des Mines (Paris)
Edgar Allen News (Sheffield)
Eidgenossische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, Berichte (Zürich)
Electrical Engineer and Merchandiser (Melbourne)
Electrical Journal (London)
Electrical Power Engineer (London)
Electrical Review (London)
Electrical Times (London)
Electronic Engineering (London)
Electroplating and Metal Finishing (London)
Elektrotechnik (Prague)
Elektrotechniski Vestnik (Ljubljana, Yugoslavia)
Elektrowärme Technik (Mindelheim)
Elliott Journal (London)
Endeavour (London)
Engenharia, Mineração e Metalurgia (Rio de Janeiro)
Engineer (London)
Engineer and Foundryman (Braamfontein, Johannesburg)
Engineering (London)
Engineering and Boiler House Review (London)
Engineering Inspection (London)
Engineering Journal (Montreal)
Engineering and Mining Journal (New York)
Engineering Research Bulletin, University of Michigan (Ann Arbor)
Engineers' Digest (London)
English Electric Journal (Stafford)
Escher-Wyss News (Zürich)

First Iron Works Association, Gazette (Saugus, Mass.)
Fizika Metallov i Metallouedenie (Moscow)
Fonderia Italiana (Milan)
Fonderie (Paris)
Forschung auf dem Gebiete des Ingenieurwesens (Düsseldorf)
Foundry (Cleveland)
Foundry and Metal Treating (Sydney)
Foundry Trade Journal (London)
Fuel (London)
Fuel Economy Review (London)
Fuel Society Journal (Sheffield)

G.E.C. Journal (London)
G.E.C. Telecommunications (Coventry)
Gas Research Board Communications (Beckenham)
Gas Times (Watford)
Gas World (London)
Gazzetta Chimica Italiana (Rome)
General Motors Engineering Journal (Detroit)
Génie Chimique (Paris)
Génie Civil (Paris)
Geologiska Föreningens Förhandlingar (Stockholm)
Giesserei (Düsseldorf)
Giessereitechnik (Berlin)
Gjuteriet (Stockholm)
Glückauf (Essen)
Government Mechanical Laboratory Bulletin (Tokyo)

Hutnické Listy (Prague)
Hutnik (Prague)
Hutnik (Poland)

IVA Ingeniörs Vetenskaps Akademien (Stockholm)
Illinois University Engineering

Experiment Station (Urbana) Circular
Bulletin
Indian Journal of Physics (Calcutta)
Industria y Química (Buenos Aires)
Industrial Chemist (London)
Industrial and Engineering Chemistry (Washington)
Industrial Finishing (Leighton Buzzard)
Industrial Gas (Leighton Buzzard)
Industrial Heating (Pittsburgh)
Industrial Heating Engineer (London)
Industrie Nationale (Paris)
Ingegneria Meccanica (Milan)
Ingenieria e Industria (Buenos Aires)
Ingeniörs Vetenskaps Akademien, Handlingar (Stockholm)
Institut pour l'Encouragement de la Recherche Scientifique, Comptes Rendus de Recherches (Brussels)
Institut Mashinovedeniya, Trenie i Iznos v Mashinakh (Moscow)
Institute of British Foundrymen, Paper (Manchester)
Institute of Fuel, Advance Copies (London)
Institute of Petroleum, I.P. Review (London)
Institution of Gas Engineers, Communications (London)
Instituto del Hierro y del Acero (Madrid)
Instituto de la Soldadura, Publicacíon (Madrid)
Instituto Sperimentale dei Metalli Leggeri, Relazione Annuale (Milan)
Instituto Nacional del Carbon Boletin Informativo (Oviedo)
Instituto Nacional de Tecnologia Boletin (Rio de Janeiro)
Instrument Engineer (Luton)
Instrument Practice (London)
Instruments in Industry (London)
Iron Age (New York)
Iron and Coal Trades Review (London)
Iron and Steel (London)
Iron and Steel Engineer (Pittsburgh)
Iron and Steel Institute, Special Reports (London)
Izvestiya Akademii Nauk S.S.S.R., Otdelenie Khimicheskikh Nauk (Moscow)
Izvestiya Akademii Nauk, S.S.S.R., Otdelenie Teknicheskikh Nauk (Moscow)
Izvestiya Akademii Nauk S.S.S.R., Seriya Fizicheskaya (Moscow)

Jernindustri (Oslo)
Jernkontorets Annaler (Stockholm)
Journal of the American Ceramic Society (Columbus, Ohio)
Journal of the American Chemical Society (Washington, D.C.)
Journal of the American Society of Naval Engineers (Washington, D.C.)
Journal of the American Water Works Association (New York)
Journal of the American Zinc Institute (New York)
Journal of Applied Chemistry (London)
Journal of Applied Mechanics (New York)
Journal of Applied Physics (New York)
Journal of the Birmingham Metallurgical Society (Birmingham)
Journal of the British Institution of Radio Engineers (London)
Journal of the British Shipbuilding Research Association (London)
Journal of the Chemical, Metallurgical and Mining Society of South Africa (Johannesburg)
Journal of Chemical Physics (New York)
Journal of the Chemical Society (London)
Journal de Chimie Physique (Paris)
Journal of Dental Research (Baltimore)
Journal of the Electrochemical Society (Baltimore)
Journal du Four Electrique (Paris)
Journal of the Franklin Institute (Lancaster, Pa.)
Journal of the Indian Chemical Society (Calcutta)
Journal d'Informations Techniques des Industries de la Fonderie (Paris)
Journal of the Institute of Australian Foundrymen (Melbourne)
Journal of the Institute of Fuel (London)
Journal of the Institute of Metals (London)
Journal of the Institute of Petroleum (London)
Journal of the Institution of Automotive and Aeronautical Engineers (Melbourne)
Journal of the Institution of Civil Engineers (London)
Journal of the Institution of Electrical Engineers (London)
Journal of the Institution of Engineers, Australia (Sydney)
Journal of the Institution of Heating and Ventilating Engineers (London)
Journal of the Institution of Locomotive Engineers (London)
Journal of the Institution of Production Engineers (London)
Journal of The Iron and Steel Institute (London)
Journal of the Junior Institution of Engineers (London)
Journal of The Liverpool Engineering Society (Liverpool)
Journal of Mechanical Laboratory (Tokyo)
Journal of the Mechanics and Physics of Solids (London)
Journal of Metals (New York)
Journal of the Optical Society of America (New York)
Journal of Petroleum Technology (Dallas, Texas)
Journal of the Physical Society of Japan (Tokyo)
Journal de Physique et le Radium (Paris)
Journal of the Royal Institute of Chemistry (London)
Journal and Proceedings of the Royal Society of New South Wales (Sydney)
Journal of Research of the National Bureau of Standards (Washington, D.C.)
Journal of the Royal Aeronautical Society (London)
Journal of the Royal Artillery (London)
Journal of the Royal Institute of British Architects (London)
Journal of the Royal Microscopical Society (London)
Journal of the Royal Society of Arts (London)
Journal of the Royal Statistical Society (London)
Journal of Scientific Instruments (London)
Journal of Scientific and Industrial Research (New Delhi)
Journal of the Scientific Research Institute (Tokyo)
Journal of the Society of Glass Technology (Sheffield)
Journal of the South African Institution of Mechanical Engineers (Johannesburg)
Journal and Transactions of the Society of Engineers (London)
Journal of the West of Scotland Iron and Steel Institute (London)

Kohászati Lapok (Budapest)

Laboratoria N.V. Philips' Gloeilampfabrieken, Separaat (Eindhoven)
Lastechniek (The Hague)
Light Metal Age (Chicago)
Light Metals (London)
Liteĭnoe Proizvodstvo (Moscow)
Lithgow Journal (Glasgow)

Machine Design (Cleveland, Ohio)
Machine Shop Magazine (London)
Machinery (Brighton)
Manchester Association of Engineers, Preprints (Manchester)
Maschinenbau und Wärmewirtschaft (Vienna)
Maschinenwelt und Elektrotechnik (Vienna)
Materials and Methods (New York)
Mechanical Engineering (New York)
Mechanical Handling (London)
Mechanical World (London)
Memoirs of the Faculty of Engineering Kyoto University (Kyoto)
Memoirs of the Faculty of Engineering Kyushu University (Fukuoka)
Memoirs of the Faculty of Technology, Tokyo Metropolitan University (Tokyo)
Memoirs of the Geological Survey of India (Calcutta)
Mémoires de la Société des Ingénieurs Civils de France (Paris)
Mémorial de l'Artillerie Française (Paris)
Metal Age (London)
Metal Bulletin (London)
Metal Finishing (New York)
Metal Finishing Journal (London)
Metal Industry (London)
Metal Progress (Cleveland, Ohio)
Metal Treating (New Rochelle, N.Y.)
Metal Treatment and Drop Forging (London)
Metalen (The Hague)
Metall (Berlin)
Metalloberfläche (Munich)
Metallurgia (Manchester)
Metallurgia Italiana (Milan)
Metallurgical Reviews (London)
Métallurgie et la Construction Mécanique (Paris)
Metalurgia y Electricidad (Madrid)
Metalworking Production (London)
Métaux–Corrosion–Industries (Paris)
Metropolitan Vickers Gazette (Manchester)
Michigan University (Ann Arbor) Engineering Research Bulletins Engineering Research Circulars
Microtecnic (Lausanne)
Mine and Quarry Engineering (London)
Mineralogical Magazine (London)
Mines Magazine (Denver, Colo.)
Mining, Electrical and Mechanical Engineer (Manchester)

Bell Telephone System Technical Publication (New York)
Bell Telephone Magazine (New York)
Berg- und hüttenmännische Monatshefte (Vienna)
Bibliographical Bulletin of Welding (Paris)
Blad för Bergshandteringens Vänner (Stockholm)
Blast Furnace and Steel Plant (Pittsburgh)
Boletim da Associação Brasileira de Metais (São Paulo)
Boletim da Associação Química do Brasil (Rio de Janeiro)
Boletim da Sociedade Geológica de Portugal (Oporto)
Boletim do INT (Rio de Janeiro)
Boletin Minero e Industrial (Bilbao)
Brennstoff–Warme–Kraft (Dusseldorf)
British Cast Iron Research Association, Journal of Research and Development (Birmingham)
British Coal Utilisation Research Association, Monthly Bulletin (London)
British Coke Research Association, Technical Papers (London)
British Dental Journal (London)
British Electrical and Allied Industries Research Association, Reports (London)
British Engineering (London)
British Iron and Steel Federation, Monthly Statistical Bulletin (London)
British Iron and Steel Research Association, Reports (London)
British Journal of Applied Physics (London)
British Steelmaker (London)
British Welding Journal (London)
Brown-Boveri Review (Baden)
Bulletin de l'Académie Polonaise des Sciences (Warsaw)
Classe Quatrième
Classe Troisième
Bulletin of the American Ceramic Society (Columbus, Ohio)
Bulletin, American Society for Testing Materials (Philadelphia)
Bulletin of the British Scientific Instrument Research Association (London)
Bulletin, British Steel Founders' Association (Sheffield)
Bulletin de Cercle d'Etudes des Métaux (St. Etienne)
Bulletin and Foundry Abstracts of the British Cast Iron Research Association (Birmingham)
Bulletin of the Institute of Metal Finishing (London)
Bulletin of the Institution of Metallurgists (London)
Bulletin of the Institution of Mining and Metallurgy (London)
Bulletin of Ohio State University Engineering Experiment Station (Columbus, O.)
Bulletin of the School of Mines and Metallurgy, University of Missouri (Minneapolis)
Bulletin des Sociétés Chimiques Belges (Brussels)
Bulletin of the University of Wisconsin, Engineering Experiment Station Series

Canada Department of Mines and Technical Surveys, Mines Branch, Research and Special Projects Reports (Ottawa)
Canadian Journal of Chemistry (Ottawa)
Canadian Journal of Physics (Ottawa)
Canadian Journal of Technology (Ottawa)
Canadian Metals (Toronto)
Canadian Mining Journal (Quebec)
Canadian Mining and Metallurgical Bulletin (Montreal)
Calore (Milan)
Castings (Sydney)
Centre de Documentation Sidérurgique, Circulaires d'Informations Techniques (Paris)
Ceramics (Leighton Buzzard)
Chaleur et Industrie (Paris)
Chartered Mechanical Engineer (London)
Chemical Age (London)
Chemical Engineering (New York)
Chemical Engineering and Mining Review (Melbourne)
Chemical and Engineering News (Washington)
Chemical Engineering Progress (New York)
Chemical & Process Engineering (London)
Chemické Listy (Prague)
Chemisch Weekblad (Amsterdam)
Chemist-Analyst (Phillipsburg, N.J.)
Chemistry and Industry (London)
Chimica e Industria (Milan)
Chimie Analytique (Paris)
Chimie et Industrie (Paris)
Chrome Dur (Paris)
Ciencia y Tecnica de la Soldadura (Madrid)
Circular of the National Bureau of Standards (Washington)
Circular of Ohio State University Engineering Experiment Station (Columbus)
Claycraft (London)
Coke and Gas (London)
Coke Review (London)
Collection of Czechoslovak Chemical Communications (Prague)
Colliery Guardian (London)
Colonial Geology and Mineral Resources (London)
Colorado School of Mines, Quarterly (Golden, Colorado)
Commonwealth Engineer (Melbourne)
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences (Paris)
Congrès du Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique (Paris)
Corrosion (Houston, Texas)
Corrosion et Anti-Corrosion (Paris)
Corrosion Prevention and Control (London)
Corrosion Technology (London)
Coventry Engineering Society Journal (Coventry)

Dansk Teknisk Tidsskrift (Copenhagen)
Demag News (Duisburg)
Discussions of the Faraday Society (London)
Documentation Métallurgique (Paris)
Doklady Akademii Nauk S.S.S.R.
Draht (English edition) (Coburg)
Draht (German edition) (Coburg)
Dyna (Barcelona)

E.S.C. News (Sheffield)
Echo des Mines (Paris)
Edgar Allen News (Sheffield)
Eidgenossische Materialprüfungs- und Versuchsantalt für Industrie, Bauwesen und Gewerbe, Berichte (Zürich)
Electrical Engineer and Merchandiser (Melbourne)
Electrical Journal (London)
Electrical Power Engineer (London)
Electrical Review (London)
Electrical Times (London)
Electronic Engineering (London)
Electroplating and Metal Finishing (London)
Elektrotechnik (Prague)
Elektrotechniski Vestnik (Ljubljana, Yugoslavia)
Elektrowärme Technik (Mindelheim)
Elliott Journal (London)
Endeavour (London)
Engenharia, Mineração e Metalurgia (Rio de Janeiro)
Engineer (London)
Engineer and Foundryman (Braamfontein, Johannesburg)
Engineering (London)
Engineering and Boiler House Review (London)
Engineering Inspection (London)
Engineering Journal (Montreal)
Engineering and Mining Journal (New York)
Engineering Research Bulletin, University of Michigan (Ann Arbor)
Engineers' Digest (London)
English Electric Journal (Stafford)
Escher-Wyss News (Zürich)

First Iron Works Association, Gazette (Saugus, Mass.)
Fizika Metallov i Metallouedenie (Moscow)
Fonderia Italiana (Milan)
Fonderie (Paris)
Forschung auf dem Gebiete des Ingenieurwesens (Düsseldorf)
Foundry (Cleveland)
Foundry and Metal Treating (Sydney)
Foundry Trade Journal (London)
Fuel (London)
Fuel Economy Review (London)
Fuel Society Journal (Sheffield)

G.E.C. Journal (London)
G.E.C. Telecommunications (Coventry)
Gas Research Board Communications (Beckenham)
Gas Times (Watford)
Gas World (London)
Gazzetta Chimica Italiana (Rome)
General Motors Engineering Journal (Detroit)
Génie Chimique (Paris)
Génie Civil (Paris)
Geologiska Föreningens Förhandlingar (Stockholm)
Giesserei (Düsseldorf)
Giessereitechnik (Berlin)
Gjuteriet (Stockholm)
Glückauf (Essen)
Government Mechanical Laboratory Bulletin (Tokyo)

Hutnické Listy (Prague)
Hutnik (Prague)
Hutnik (Poland)

IVA Ingeniörs Vetenskaps Akademien (Stockholm)
Illinois University Engineering

Experiment Station (Urbana)
Circular
Bulletin
Indian Journal of Physics (Calcutta)
Industria y Química (Buenos Aires)
Industrial Chemist (London)
Industrial and Engineering Chemistry (Washington)
Industrial Finishing (Leighton Buzzard)
Industrial Gas (Leighton Buzzard)
Industrial Heating (Pittsburgh)
Industrial Heating Engineer (London)
Industrie Nationale (Paris)
Ingegneria Meccanica (Milan)
Ingenieria e Industria (Buenos Aires)
Ingeniörs Vetenskaps Akademien, Handlingar (Stockholm)
Institut pour l'Encouragement de la Recherche Scientifique, Comptes Rendus de Recherches (Brussels)
Institut Mashinovedeniya, Trenie i Iznos v Mashinakh (Moscow)
Institute of British Foundrymen, Paper (Manchester)
Institute of Fuel, Advance Copies (London)
Institute of Petroleum, I.P. Review (London)
Institution of Gas Engineers, Communications (London)
Instituto del Hierro y del Acero (Madrid)
Instituto de la Soldadura, Publicacion (Madrid)
Instituto Sperimentale dei Metalli Leggeri, Relazione Annuale (Milan)
Instituto Nacional del Carbon Boletin Informativo (Oviedo)
Instituto Nacional de Tecnologia Boletin (Rio de Janeiro)
Instrument Engineer (Luton)
Instrument Practice (London)
Instruments in Industry (London)
Iron Age (New York)
Iron and Coal Trades Review (London)
Iron and Steel (London)
Iron and Steel Engineer (Pittsburgh)
Iron and Steel Institute, Special Reports (London)
Izvestiya Akademii Nauk S.S.S.R., Otdelenie Khimicheskikh Nauk (Moscow)
Izvestiya Akademii Nauk, S.S.S.R., Otdelenie Teknicheskikh Nauk (Moscow)
Izvestiya Akademii Nauk S.S.S.R., Seriya Fizicheskaya (Moscow)

Jernindustri (Oslo)
Jernkontorets Annaler (Stockholm)
Journal of the American Ceramic Society (Columbus, Ohio)
Journal of the American Chemical Society (Washington, D.C.)
Journal of the American Society of Naval Engineers (Washington, D.C.)
Journal of the American Water Works Association (New York)
Journal of the American Zinc Institute (New York)
Journal of Applied Chemistry (London)
Journal of Applied Mechanics (New York)
Journal of Applied Physics (New York)
Journal of the Birmingham Metallurgical Society (Birmingham)
Journal of the British Institution of Radio Engineers (London)
Journal of the British Shipbuilding Research Association (London)
Journal of the Chemical, Metallurgical and Mining Society of South Africa (Johannesburg)
Journal of Chemical Physics (New York)
Journal of the Chemical Society (London)
Journal de Chimie Physique (Paris)
Journal of Dental Research (Baltimore)
Journal of the Electrochemical Society (Baltimore)
Journal du Four Electrique (Paris)
Journal of the Franklin Institute (Lancaster, Pa.)
Journal of the Indian Chemical Society (Calcutta)
Journal d'Informations Techniques des Industries de la Fonderie (Paris)
Journal of the Institute of Australian Foundrymen (Melbourne)
Journal of the Institute of Fuel (London)
Journal of the Institute of Metals (London)
Journal of the Institute of Petroleum (London)
Journal of the Institution of Automotive and Aeronautical Engineers (Melbourne)
Journal of the Institution of Civil Engineers (London)
Journal of the Institution of Electrical Engineers (London)
Journal of the Institution of Engineers, Australia (Sydney)
Journal of the Institution of Heating and Ventilating Engineers (London)
Journal of the Institution of Locomotive Engineers (London)
Journal of the Institution of Production Engineers (London)
Journal of The Iron and Steel Institute (London)
Journal of the Junior Institution of Engineers (London)
Journal of The Liverpool Engineering Society (Liverpool)
Journal of Mechanical Laboratory (Tokyo)
Journal of the Mechanics and Physics of Solids (London)
Journal of Metals (New York)
Journal of the Optical Society of America (New York)
Journal of Petroleum Technology (Dallas, Texas)
Journal of the Physical Society of Japan (Tokyo)
Journal de Physique et le Radium (Paris)
Journal of the Royal Institute of Chemistry (London)
Journal and Proceedings of the Royal Society of New South Wales (Sydney)
Journal of Research of the National Bureau of Standards (Washington, D.C.)
Journal of the Royal Aeronautical Society (London)
Journal of the Royal Artillery (London)
Journal of the Royal Institute of British Architects (London)
Journal of the Royal Microscopical Society (London)
Journal of the Royal Society of Arts (London)
Journal of the Royal Statistical Society (London)
Journal of Scientific Instruments (London)
Journal of Scientific and Industrial Research (New Delhi)
Journal of the Scientific Research Institute (Tokyo)
Journal of the Society of Glass Technology (Sheffield)
Journal of the South African Institution of Mechanical Engineers (Johannesburg)
Journal and Transactions of the Society of Engineers (London)
Journal of the West of Scotland Iron and Steel Institute (London)

Kohászati Lapok (Budapest)

Laboratoria N.V. Philips' Gloeilampfabrieken, Separaat (Eindhoven)
Lastechniek (The Hague)
Light Metal Age (Chicago)
Light Metals (London)
Liteĭnoe Proizvodstvo (Moscow)
Lithgow Journal (Glasgow)

Machine Design (Cleveland, Ohio)
Machine Shop Magazine (London)
Machinery (Brighton)
Manchester Association of Engineers, Preprints (Manchester)
Maschinenbau und Wärmewirtschaft (Vienna)
Maschinenwelt und Elektrotechnik (Vienna)
Materials and Methods (New York)
Mechanical Engineering (New York)
Mechanical Handling (London)
Mechanical World (London)
Memoirs of the Faculty of Engineering Kyoto University (Kyoto)
Memoirs of the Faculty of Engineering Kyushu University (Fukuoka)
Memoirs of the Faculty of Technology, Tokyo Metropolitan University (Tokyo)
Memoirs of the Geological Survey of India (Calcutta)
Mémoires de la Société des Ingénieurs Civils de France (Paris)
Mémorial de l'Artillerie Française (Paris)
Metal Age (London)
Metal Bulletin (London)
Metal Finishing (New York)
Metal Finishing Journal (London)
Metal Industry (London)
Metal Progress (Cleveland, Ohio)
Metal Treating (New Rochelle, N.Y.)
Metal Treatment and Drop Forging (London)
Metalen (The Hague)
Metall (Berlin)
Metalloberfläche (Munich)
Metallurgia (Manchester)
Metallurgia Italiana (Milan)
Metallurgical Reviews (London)
Métallurgie et la Construction Mécanique (Paris)
Metalurgia y Electricidad (Madrid)
Metalworking Production (London)
Métaux–Corrosion–Industries (Paris)
Metropolitan Vickers Gazette (Manchester)
Michigan University (Ann Arbor)
Engineering Research Bulletins
Engineering Research Circulars
Microtecnic (Lausanne)
Mine and Quarry Engineering (London)
Mineralogical Magazine (London)
Mines Magazine (Denver, Colo.)
Mining, Electrical and Mechanical Engineer (Manchester)

Mining Engineering (New York)
Mining Journal (London)
Mining Magazine (London)
Mitteilungen aus dem Max-Planck-Institut für Eisenforschung (Düsseldorf)
Modern Castings and American Foundryman (Des Plaines, Ill.)
Modern Foundry (Melbourne)
Modern Metals (Chicago)
Murex Review (Rainham, Essex)

Nachrichten aus der Eisen-Bibliothek der Georg Fischer Aktiengesellschaft (A.G.) (Schaffhausen)
National Physical Laboratory, Reports (Teddington)
National Science Foundation Translations (Washington)
Nature (London)
Neue Hütte (Berlin)
New Zealand Engineering (Wellington)
New Zealand Journal of Science and Technology (Wellington)
Nickel Bulletin (London)
Nippon Kinzoku Gakkai-Si (Sendai)
Non-Destructive Testing (Evanston, Ill.)
Norsk Geologisk Tidsskrift (Oslo)

Oil Engine and Gas Turbine (London)
Operational Research Quarterly (London)
Optima (Johannesburg)
Osaka City University, Journal of the Institute of Polytechnics (Osaka)
Osaka University, Faculty of Engineering Technology Reports (Osaka)
Overseas Engineer (London)

PACT (Prevention des Accidents Contrôles Techniques Hygiene et Maladies Professionnelles) (Paris)
Paliva (Prague)
Peintures, Pigments, Vernis (Paris)
Philippine Geologist (Manila)
Philips Research Reports (Eindhoven)
Philips Technical Review (Amsterdam)
Philosophical Magazine (London)
Philosophical Transactions of the Royal Society (London)
Physical Review (New York)
Planseeberichte für Pulvermetallurgie (Reutte, Tyrol)
Plating (Jenkintown, Pa.)
Post Office Electrical Engineers' Journal (Epsom)
Powder Metallurgy Bulletin (Yonkers, N.Y.)
Prace Instytutów Mechaniki (Warsaw)
Prace Instytutów Ministerstwa Hutnictwa (Poland)
Pratique du Soudage (Brussels)
Precision Metal Molding (Cleveland)
Proceedings, American Gas Association (New York)
Proceedings of the American Society for Testing Materials (Philadelphia)
Proceedings of the Annual Convention of the American Electroplaters' Society (Jenkintown, Pa.)
Proceedings, Australasian Institute of Mining and Metallurgy (Melbourne)
Proceedings of the Australian Institute of Metals (Melbourne)
Proceedings of the Cambridge Philosophical Society (London)
Proceedings, Chemical Engineering Group (London)
Proceedings, Diesel Engine Users' Association (London)
Proceedings of the Durham Philosophical Society (Durham)
Proceedings of the Ebbw Vale Metallurgical Society (Ebbw Vale)
Proceedings of the Indian Academy of Sciences (Bangalore)
Proceedings of the Indiana Academy of Sciences (Greencastle, Ind.)
Proceedings of the Institute of Australian Foundrymen (Melbourne)
Proceedings of the Institute of British Foundrymen (Manchester)
Proceedings of the Institution of Electrical Engineers (London)
Proceedings, Institution of Mechanical Engineers (London)
Proceedings of the Institution of Mechanical Engineers, Automobile Division (London)
Proceedings of the Japan Academy (Tokyo)
Proceedings of the Lincolnshire Iron and Steel Institute (Scunthorpe)
Proceedings, Metal Powder Association (New York)
Proceedings, Natural Gas Department of the American Gas Association (New York)
Proceedings of the Physical Society (London)
Proceedings of the Royal Canadian Institute (Toronto)
Proceedings of the Royal Institution of Great Britain (London)
Proceedings of the Royal Society (London)
Proceedings of the Royal Society of Edinburgh (Edinburgh)
Proceedings of the Society of Experimental Stress Analysis (Cambridge, Mass.)
Proceedings of the South Wales Institute of Engineers (Cardiff)
Proceedings of the Staffordshire Iron and Steel Institute (Walsall)
Process Control and Automation (London)
Product Engineering (New York)
Product Finishing (London)
Products Finishing (Cincinnati)
Pro-Metal (Berne)
Przeglad Odlewnictwa (Cracow)
Przeglad Techniczny (Warsaw and Lodz)
Publications de l'Association des Ingénieurs de la Faculté Polytechnique de Mons (Mons)
Publications de l'Institut de Recherches de la Sidérurgie (St. Germain-en-Laye)
Purdue University, Engineering Experimental Department (Lafayette, Ind.)
Engineering Extension Series
Engineering Research Series

Quarterly Journal of the Geological, Mining, and Metallurgical Society of India (Calcutta)
Quarterly Journal of Mechanics and Applied Mathematics (Oxford)
Queensland Government Mining Journal (Brisbane)

Radex Rundschau (Radenthein)
Railway Gazette (London)
Railway Steel Topics (Sheffield)
Recherche Aéronautique (Paris)
Records of the Geological Survey of India (Calcutta)
Recueil des Travaux Chimiques des Pays-Bas (The Hague)
Refractories Journal (London)
Regional Technical Meetings of the American Iron and Steel Institute (New York)
Reports of the Scientific Research Institute (Tokyo)
Research (London)
Research Association of British Paint, Colour and Varnish Manufacturers' Review (Teddington)
Review of Scientific Instruments (New York)
Reviews of Modern Physics (New York)
Reviews of Pure and Applied Chemistry (Melbourne)
Revista de Ciencia Aplicada (Madrid)
Revista de Quimica Industrial (Rio de Janeiro)
Revue de l'Aluminium (Paris)
Revue de la Faculté des Sciences de l'Université d'Istanbul
Revue Générale de Mécanique (Paris)
Revue de l'Industrie Minérale (St. Etienne)
Revue de Métallurgie (Paris)
Revue des Produits Chimiques (Paris)
Revue de la Soudure (Lastijdschrift) (Brussels)
Revue du Nickel (Paris)
Revue de la Société Royale Belge des Ingénieurs et des Industriels (Bruxelles)
Revue Technique Luxembourgeoise (Luxembourg)
Revue Universelle des Mines (Liége)
Rheology Bulletin (New York)
Ricerca Scientifica (Rome)
Roll'schen Eisenwerke A.G. (Gerlafingen, Switzerland)
Mitteilungen
Werkzeitung
Royal School of Mines Journal (London)
Rudarsko-Metalurski Zbornik (Ljubljana)

S.A.E. Journal (New York)
Schweissen und Schneiden (Brunswick)
Schweisstechnik (Vienna)
Schweizer Archiv für Wissenschaft und Technik (Solothurn, Switzerland)
Science (Washington)
Science Abstracts (London)
Science and Engineering (Calcutta)
Science Reports of the Tôhoku University (Sendai, Japan)
Science Reports of the Research Institutes, Tôhoku University (Sendai, Japan)
Scientific Proceedings of the Royal Dublin Society
Sheet Metal Industries (London)
Shipbuilder and Marine Engine-Builder (Newcastle-upon-Tyne)
Silicates Industriels (Brussels)
Slévárenství (Prague)
Soudage et Techniques Connexes (Paris)
Spectrographic News Letter (Glendale, Calif.)
Stahl und Eisen (Düsseldorf)
Stainless Steel Review (London)
Stal (Moscow)
Stanki i Instrument (Moscow)
Statens Provningsanstalt (Stockholm)
Berättelse
Meddelande
Steam Engineer (London)
Steel (Cleveland, Ohio)
Steel Processing (Pittsburgh)
Steelways (New York)
Structural Engineer (London)

Suiyokwai-Shi, Transactions of the Mining and Metallurgical Alumni Association (Japan)
Sulzer Technical Review (Winterthur)
Sumitomo Metals (Osaka)
Sveriges Geologiska Undersökning, Årsbok (Stockholm)
Svetsaren (Gothenburg)
Swansea and District **Metallurgical Society, Advance Copies** (Gorseinon)

Technical Reports of The **Engineering Research Institute, Kyoto University** (Kyoto)
Technik (Berlin)
Technique et Humanisme (Liège)
Techniques et Civilisations (St. Germain-en-Laye)
Technische Mitteilungen (Rheinhausen)
Technische Mitteilungen Krupp (Essen)
Tecnica e Industria (Buenos Aires)
Tecnica Metalúrgica (Barcelona)
Teknillisen Kemian Aikakausilehti (Helsinki)
Teknisk Tidskrift (Stockholm)
Teknisk Ukeblad (Oslo)
Tetsu-to-Hagane (Tokyo)
Tidsskrift for Kjemi, Bergvesen og Metallurgi (Oslo)
Times Review of Industry (London)
Tin and its Uses (Greenford)
Tisco (Jameshedpur)
Tokyo University, Journal of the Faculty of Engineering (Tokyo)
Torch (London)
Transactions of the American Foundrymen's Society (Chicago)
Transactions of the American Institute of Electrical Engineers (New York)
Transactions of the American Institute of Mining and Metallurgical Engineers (New York)
Transactions of the American Society of Mechanical Engineers (New York)
Transactions of the American Society for Metals (Cleveland, Ohio)
Transactions of the British Ceramic Society (Stoke-on-Trent)
Transactions of the Canadian Institute of Mining and Metallurgy (Montreal)
Transactions of the Danish Academy of Technical Sciences (Copenhagen)
Transactions of the Faraday Society (London)
Transactions of the Indian Institute of Metals (New Delhi)
Transactions of the Institute of Marine Engineers (London)
Transactions of The Institute of Metal Finishing (London)
Transactions of the Institution of Chemical Engineers (London)
Transactions of the Institution of Engineers and Shipbuilders in Scotland (Glasgow)
Transactions, Institution of Gas Engineers (London)
Transactions of the Institution of Mining Engineers (London)
Transactions of the Institution of Mining and Metallurgy (London)
Transactions of the Institution of Naval Architects (London)
Transactions of the Liverpool Engineering Society (Liverpool)
Transactions, Manchester Association of Engineers (Manchester)
Transactions of the Mining, Geological and Metallurgical Institute of India (Calcutta)
Transactions of the Newcomen Society (London)
Transactions of the North East Coast Institution of Engineers and Shipbuilders (Newcastle-on-Tyne)
Transactions of the Royal Canadian Institute (Toronto)
Transactions of the Royal Society of Canada (Ottawa)
Transactions of the Society of Automotive Engineers (New York)
Transactions of the Society of Instrument Technology (London)
Transactions of the South African Institute of Electrical Engineers (Johannesburg)

United Effort (Pittsburgh)
United States Bureau of Mines (Washington, D.C.)
Bulletin
Information Circular
Reports of Investigations
United States Geological Survey, Bulletin (Washington)
Usco Magazine (Pretoria)
Usine Nouvelle (Paris)

Vacuum (London)
Varilna Tehnika (Ljubljana)
Värmländska Bergsmannaföreningens Annaler (Filipstad, Sweden)
Vestnik Mashinostroenniya (Moscow)
Vickers Magazine (London)

Waseda University, Report of the Casting Research Laboratory (Tokyo)
Welder (Waltham Cross)
Welding Journal (New York)
Welding and Metal Fabrication (London)
Welding Research Council, Welding Research Council Bulletin Series (New York)
Werkstoffe und Korrosion (Mannheim)
Werkszeitung der Schoeller-Bleckmann Stahlwerke (Vienna)
Western Metals (Los Angeles)
Wild-Barfield Heat-Treatment Journal (Watford, Herts)
Wire Industry (London)
Wire Production (London)
Wire and Wire Products (Stamford, Conn.)

Yearbook of the American Iron and Steel Institute (New York)
Yearbook of the Coke Oven Managers' Association (London)
Yearly Proceedings of the Association of Iron and Steel Engineers (Pittsburgh)

Zastita Materijala (Belgrade)
Zavodskaya Laboratoriya (Moscow)
Zeitschrift für Erzbergbau und Metallhüttenwesen (Stuttgart)
Zeitschrift für Metallkunde (Stuttgart)
Zeitschrift des Vereines deutscher Ingenieure (Düsseldorf)
Zhurnal Analiticheskoi Khimii (Moscow)
Zhurnal Fizicheskoi Khimii (Moscow)
Zhurnal Prikladnoi Khimii (Moscow)
Zhurnal Tekhnicheskoi Fiziki (Moscow)
Zváranie (Bratislava)

ABSTRACTS

MINERAL RESOURCES

The Iron Ore Deposits of Minnesota and their Importance for the Mining Industry. H. Kern. (*Berg. Hüttenmänn. Monatsh.*, 1955, **100**, Feb., 97–103).

Blast-Furnace Raw Materials. S. Visvanathan and S. N. Anant Narayan. (*Tisco*, 1955, **2**, July, 98–107). The author describes the quality, size, and location of iron-ore deposits in India. The use and availability of limestone for the indigenous iron industry and the evaluation of coke as a blast-furnace fuel are dealt with.—L. E. W.

ORES—MINING AND TREATMENT

Ore Unloader Economical in the Consumption of Power. K. E. Lewis. (*Blast Furn. Steel Plant*, 1955, **43**, Aug., 909–912). An account is given of a new unloader designed and built by Dravo Corporation, U.S.A., designed for a free digging rate of 1700 tons/h of ore.—B. G. B.

The Importance of Areal Clarifying Capacity in Devices for the Mechanical Separation of Solids from Liquids. H. Trawinski. (*Radex Rundschau*, 1955, Mar., 369–373). The concept of capacity per unit of clarifying area is defined and discussed. From static settling systems it is extended to centrifuges and hydro-cyclones. The adoption of intensity and quantity parameters is advocated.—E. C.

Hydro-Metallurgical Methods as a Complement to Beneficiation. G. Björling. (*Tekn. Tidskr.*, 1955, **85**, Apr. 12, 333–337). [In Swedish]. Details are given of the chemical bases of leaching methods used in the treatment of low-grade ores to recover gold, silver, copper, cobalt, and uranium.

Modern Methods of Iron Ore Beneficiation. S. Sjöberg. (*Tekn. Tidskr.*, 1955, **85**, Mar. 8, 205–208). [In Swedish]. Recent developments in crushing, magnetic separation, sink and float methods, flotation, and water removal are dealt with.—G. G. K.

Sintering of Fines Made Possible by Producing Iron-Rich Metallurgical Iron Coke. H. Barking and C. Eymann. (*Stahl u. Eisen*, 1955, **75**, June 2, 722–723). The authors present an economic consideration of the use of iron coke containing up to 35% Fe. The process is competitive with the use of conventional metallurgical coke.—T. G.

Modern Dressing Processes as the Basis of Increased Steel

Supplies. H. Kirchberg. (*Met. u. Giesserei Techn.*, 1951, **1**, Sept., 257–260). A brief survey of recent developments in ore dressing, with particular reference to electrostatic and flotation methods, is given.—L. J. L.

Recent Advances in the Understanding of Sinterability. J. Vacek. (*Hutnické Listy*, 1955, **10**, (8), 469–479). [In Czech]. Small additions of other metals were found beneficial in sintering Mo, Cu, Ni, and W, depending on the difference in the atomic radii between the addition and the base metal, the difference between their respective melting points, and the actual sintering temperature.—P. F.

FUEL—PREPARATION, PROPERTIES, AND USES

Control of Pressure in Furnaces. (*Fonderie*, 1955, Mar., 4434–4435).

Gas Combustion Equipment. A. D. Wilcox. (*Metal Progress*, 1955, **67**, June, 95–99).

Problems of Power Economy in Ironworks. B. Marschewski. (*Met. u. Giesserei Techn.*, 1951, **1**, Aug., 238–240). The following " fundamental requirements " for furnace-gas purification are listed: (i) gases should be cooled down until water vapour is separated; (ii) gases used for heating should contain a maximum of 0·1–0·5 g of dust per cubic metre of gas; (iii) gases used for generation of power should not contain more than 0·01–0·03 g/m^3 of dust. The use of gas turbines is advocated.—L. J. L.

Metallic Recuperators. L. S. Brown. (*Coke Gas*, 1955, **17**, Mar., 108–110; Apr., 152–155; May, 194–199; June, 236–238). A detailed discussion of the principles and practice of recuperation is given, with special reference to the design and applications of metallic recuperators. Recuperators, regenerators, and waste-heat boilers are defined. A simple counterflow pipe recuperator, and a simple reversing regenerating system are shown diagrammatically. Cast-iron Newton needle recuperators are considered in detail. Several arrangements of recuperators are illustrated, and the recuperators are shown in their refractory settings. Temperature gradients for counter flow, parallel flow, and cross flow are given. The advantages of recuperation are discussed, with examples of fuel saving with preheating of combustion air and of excess air. Effects on flame temperatures are examined, and some data on theoretical calculated flame temperatures for various fuels are given graphically.—T. E. D.

Iron Heat Exchangers and Their Use in Metallurgy. (*Mét. Constr. Mécan.*, 1955, **87**, June, 529–533).

Chemistry of Coal. I. G. C. Dryden. (*Research*, 1955, **8**, May, 183–190). Correct and full utilization of coal depends on the knowledge of its chemical constitution. A survey is made of early work and current fundamental research, and the latest views on the structure and basic units of coal are summarized.—K. E. J.

The Coalfields of Great Britain and Their Future Development. E. H. Browne. (*Trans. Inst. Min. Eng.*, 1954–55, **114**, May, 705–742).

The Properties of Washing Water and Their Importance in Coal Beneficiation. P. G. Meerman. (*Glückauf*, 1955, **91**, June 4, 652–655).

Continental Coking Practice. G. Cellan-Jones, A. Steding, and P. Veit. (*Yearbook Coke Oven Man. Assoc.*, 1955, 279–289). Particular reference is made to by-product recovery in the Didier–Kogag–Hinselmann process, including ammonia recovery, and H_2S removal. Coke-oven operation is also described.—T. E. D.

A Study of Temperature Conditions in a Coke Oven. D. J. Millard. (*J. Inst. Fuel*, 1955, **28**, July, 345–351). The use of the heat-flow equation to calculate temperature conditions in a coke-oven charge is considered. Provided the 'heat generation' term is used, the agreement between observed and calculated temperature histories is satisfactory. It is confirmed that the coking process is endothermic below about 700° C and exothermic above.—D. L. C. P.

The Application of Selective and Petrographic Beneficiation to Increasing the Range of Coking Coals and Improving the Properties of the Coke. C. Abramski. (*Glückauf*, 1955, **91**, June 18, 714–727). The Longwy–Burstlein process of coking-coal preparation is studied critically in its application to German coking coals.—L. D. H.

Statistical Study of the Scattering of Results in the MICUM and the IRSID Coke Tests. J. Ulmo, Ch. G. Thibaut, P. Vigneron, and B. Menuet-Guilbaud. (*Rev. Mét.*, 1954, **51**, Dec., 869–894). The purpose of this investigation was to study the scatter of the MICUM and IRSID characteristics. By careful sampling, the scatter due to sampling and to the drum test could be evaluated. As a result, sampling more in keeping with current plant practice was produced.—G. E. D.

Chairman's Inaugural Address. H. D. Greenwood. (*Yearbook Coke Oven Man. Assoc.*, 1955, 131–137). Coke-oven capacity and coke production from 1947 to 1953, and future trends 1953–1958 are surveyed. Distribution of coking capacity between the National Coal Board, the iron and steel industry, and independent ovens is given. Location of British coking plants is mentioned, and the production of coke and gas is discussed in relation to industrial and domestic requirements.—T. E. D.

Considerations of Accident Prevention as a Factor in the Design and Construction of Coking Plants. W. Dawes. (*Yearbook Coke Oven Man. Assoc.*, 1955, 211–239).

Coke Formation: A Macro Polymerisation Reaction. H. L. Riley. (*Brit. Coke Res. Assoc.*, Sixth Conference, 1953, Oct. 28, 2–7). The strength of chemical bonds is discussed in relation to the properties of polymers. The behaviour of polymers on carbonization is mentioned. The structure of coal and the mechanism of carbonization are examined.—T. E. D.

Some New Carbonization Processes Under Development and their Relation to Established Practice. D. T. Barritt and T. Kennaway. (*Yearbook Coke Oven Man. Assoc.*, 1955, 147–193). The history of coking practice is outlined and new methods suitable for carbonizing weakly coking coals are described.

Coal Tar Fuels. E. Brett-Davies. (*J. Junior Inst. Eng.*, 1955, **65**, Apr., 185–206). The specifications and properties of the 6 grades of liquid coal-tar fuels are given. Mechanism of combustion is discussed in relation to their uses, and types of burner installations are suggested.—T. E. D.

The Sampling and Determination of Moisture of Coke. D. H. Ward. (*Yearbook Coke Oven Man. Assoc.*, 1955, 259–278). Methods of sampling are discussed and recommendations made. A statistical examination of the problem is given, and sources of error are suggested.—T. E. D.

Fuel and the Ironfounding Industry. J. G. Pearce. (*J. Inst. Fuel*, 1955, **28**, July, 351–353). Specifications for foundry coke are considered, and deterioration in quality commented on. The hot-blast cupola is mentioned.—D. L. C. P.

The Microscopic Study of Coke. E. Perez Blanco. (*Inst. Nac. Carbon Bol. Inf.*, 1955, **4**, Mar., 77–83). [In Spanish]. The application of microscopic techniques to the study of the transformation of coal into coke and to the determination of the properties of the coke is considered briefly. Details of the technique of quantitative microscopical analysis of coke are given and illustrated by means of a practical example. A relationship between the mechanical strength of the coke and its micro-composition can be established.—P. S.

Modern Gas Producers for Poor Gas. P. Gauthier. (*Usine Nouvelle*, 1955, Apr., 45–51). These plants provide an excellent solution for a number of gas-heating problems where a poor gas (1000–2000 cal/m^3 at 0° C and 760 mm Hg) is required, such as in metallurgical, glass, and ceramic furnaces.

Contribution to the Methods of Determining Dust Contents in Blast-Furnace Gas. Ch. G. Thibaut, D. Sanna, and F. Douez. (*Rev. Mét.*, 1955, **52**, June, 485–507). Apparatus is described for the measurement of the dust content of blast-furnace gas. An accuracy of about 5% is claimed for the common concentration met with in practice. The sampled gas is collected in a chamber, maintained above the dew-point temperature, where it is filtered on paper or flannel according to the dust content. An attempt has been made to define the necessary condition for accurate and reproducible results.

Recovery of Zinc from Blast-Furnace Flue Dust. H. Zieler. (*Stahl u. Eisen*, 1955, **75**, July 28, 975–978). The author describes the sources which introduce zinc into the blast-furnace and its removal by filtering the flue dust. He quotes as example for the zinc balance sheet a minette-base burden. About two-thirds of the zinc content of the burden is filtered out as zinc or zinc-oxide dust. He then deals with the various processes used in the recovery of zinc.—T. G.

Electrical Cleaning of Gases. D. O. Heinrich. (*BWK*, 1955, **7**, Aug., 346–350; Sept., 389–394).

Gas-Cleaning Plant for India. (*Overseas Eng.*, 1955, **28**, June, 404). Two new blast-furnaces of the Indian Iron and Steel Co., Ltd., at Burnpur, Bengal, will be equipped with Lodge–Cottrell cleaning plant capable of handling 12 million ft^3/h.—U. E.

New Phase in the Evolution of Blast Furnace Gas Engines. A. Vamdeghen, A. Britte, and P. Laval. (*Acier, Stahl, Steel*, 1955, **20**, June, 263–266). The development of and recent improvements to the Cockerill "dual fuel" engine are described.—M. D. J. B.

TEMPERATURE MEASUREMENT AND CONTROL

Temperature Measurements in Low Velocity High Temperature Gas Streams. G. Srikantiah and A. Ramachandran. (*J. Indian Inst. Science*, 1955, **37**, Jan., Section B, 41–57). A review is made of methods of measuring gas temperatures under these conditions. Special shielded thermocouples have been found satisfactory for temperatures up to 1800° C and a heated shielded thermocouple up to 2000° F. A suction probe gave accurate results up to 2000° F. A thermodynamic method gave the best results between 1600° and 2300° F.

Electrical Parasites Hamper Temperature Measurement. D. J. Pearse. (*Steel Processing*, 1955, **41**, Jan., 22–23, 52). The author describes how errors can be introduced into thermoelectric temperature measuring circuits by the pick-up of stray alternating currents from nearby electrical machinery, power lines, heating elements, etc., and methods of avoiding them.—P. M. C.

Thermocouple Immersion Errors. J. M. Berry and D. L. Martin. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 95). Two types of error are discussed: those due to the thermocouple not being thermoelectrically homogeneous and subjected to a temperature gradient, and those due to the conduction of heat to or from the junction of the couple.

REFRACTORY MATERIALS

Recent Developments in Refractories—Their Effect on Steelmaking. H. Parnham. (*West Scotland Iron Steel Inst.*, Paper No. 482, April 15, 1955). After considering the raw materials available for refractories in the basic O.H. furnace, the author reviews the properties of the newer British silica materials and discusses in detail their application to various parts of the furnace.—L. E. W.

New Kinds of Basic Refractories. W. Szymborski. (*Prace Inst. Ministerstwa Hutnictwa*, 1955, **7**, (2–4), 85–90). [In Polish]. In view of the lack of home deposits of magnesite, experiments have been carried out on the technology of the production of stabilized dolomite clinker. The results of these experiments, as well as the experimental production of stabilized dolomite, dolomite–magnesite, and chrome–magnesite refractories, are described.—V. G.

Progress Report on Cermets. F. W. Glaser. (*Metal Progress*, 1955, **67**, Apr., 77–82, 138). Recent developments in this field are discussed. Details are given of materials which have recently been found unsuitable for use at high temperatures and of materials which have satisfactory properties.—B. G. B.

Solid-State Reactions and Dielectric Properties in the Systems Magnesia–Zirconia–Titania and Lime–Zirconia–Titania. L. W. Coughanour, R. S. Roth, S. Marzullo, and F. E. Sennett. (*J. Res. Nat. Bur. Stand.*, 1955, **54**, Apr., 191–199).

Physical Phenomena Occurring in Solids under Load. W. Späth. (*Radex Rundschau*, 1955, Mar., 353–368; May/June, 418–430). The first part of this article deals with phenomena occurring in solids under stress in general, the second part deals specifically with refractory materials. Included are internal friction, ultrasonic vibrations produced by yielding, heating effects accompanying plastic deformation, molecular sliding, thixotropy, internal stress relief, fatigue behaviour, and creep. Particular attention is given to creep in refractories.

E.M.F. Measurements in the Systems FeO–Al_2O_3 and MgO–Al_2O_3, and Observations on the Diffusion of FeO in Al_2O_3 at 1500° C. W. A. Fischer. (*Silicates Indust.*, 1955, **20**, June-July, 244–254). [In German]. An apparatus for the measurement of electro-chemical potentials at high temperatures is described, and results of experiments on binary oxide systems are given. Volume changes corresponding to the Kirkendall effect, so far only observed in metals, were found in studying diffusion in the FeO–Al_2O_3 system, and the diffusion coefficient of iron in the system was determined.—P. F.

Some Developments in Open Hearth Refractories Policy. G. R. Bashforth. (*Refract. J.*, 1955, **31**, May, 198–209).

Some Factors affecting the Significance of Refractoriness-under-Load. A. H. B. Cross. (*Trans. Brit. Ceram. Soc.*, 1955, **54**, Aug., 461–476). The following are considered, as important in establishing the reproducibility of the refractoriness-under-load test: test-piece details; temperature measurement; rates of heating; temperature uniformity; measurement of rate of subsidence.—D. L. C. P.

Refractories in the Iron and Steel Industry: I. Alumino-Silicates; II. Alumino-Silicates: Corrosion Resistance; III. Refractories in the Blast Furnace; IV. Other Applications. Helen Towers. (*Iron Steel*, 1955, **28**, Feb., 55–59; Mar., 101–105, 108; Apr., 129–134; May, 173–176). Part I deals with the alumino-silicate group. Their constitution is discussed and its relationship with mechanical strength and thermal shock resistance is considered. The resistance to corrosion of this group, or the reaction between the brick and the external gas or liquid phase, is discussed in Part 2. Part 3 deals specifically with blast-furnace refractories, the use of carbon bricks being discussed first. The types of refractories used in the stack, bosh, and hearth are then considered, and attack by carbon monoxide and alkalis is discussed. In Part 4, the remaining common applications of alumino-silicates in the iron and steel industry are discussed, with emphasis on blast-furnace stoves and ladles, and on the steel-works casting pit.—G. F.

Titanium-Carbide-Base Cermets for High Temperature Service. K. Pfaffinger, H. Blumenthal, and F. W. Glaser. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 94b). The developments of these cermets containing 25–65% of nickel–chromium or nickel–chromium–cobalt binder is described.—B. G. B.

Carbon Refractories for Blast-Furnaces. J. Holzhey. (*Metallurgie*, 1955, **5**, Apr., 134–144).

The Effect of Pig Iron and Slag on Blast-Furnace Carbon Refractories. W. Küntscher and J. Holzhey. (*Metallurgie*, 1955, **5**, Apr., 128–132). Laboratory experiments have shown that at 1300° C and above carbon refractories are noticeably affected by dissolution of carbon in pig iron. This effect will be increased by an increase in Mn content, and will be decreased by an increase in Si content. In the experiments with slag, the surface of the crucibles was not visibly affected, but at 1600° C there was a considerable decrease in FeO and MnO content, which was attributed to the reducing effect of carbon.—L. J. L.

The Use of Carbon Bricks for Hearth Bottom and Hearth Walls of Blast-Furnaces from the Point of View of Thermal Efficiency. R. Baake and J. Tischendorf. (*Metallurgie*, 1955, **5**, Apr., 123–127). The effect of thermal conductivity on the heating process, temperature distribution, and heat loss has been calculated. The uselessness of water-cooling is demonstrated. The use of carbon refractories of low thermal conductivity and good chemical and mechanical properties is advocated.—L. J. L.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Pig Iron for the Sheffield Steel Industry. I. C. Malcolm. (*E.S.C. News*, 1955, **9**, (1), 3–9).

Rapid Method of Relining a Blast Furnace. B. Vezzani. (*Iron Steel Eng.*, 1955, **32**, May, 111–117). The author describes the advanced planning which made possible the relining of an 18 ft 6 in. blast-furnace in 15½ days.—M. D. J. B.

The Layout of an Air-Cooling System in the Hearth Bottom of Blast-Furnaces. J. Tischendorf. (*Metallurgie*, 1955, **5**, Apr., 132–134). The use of carbon refractories brings about an increase in the temperature of the concrete foundations of blast-furnaces. A practical example of reducing this temperature by means of a system of air-cooling vents is given.

Investigations on Hot Blast Stoves. K. Kessels. (*Stahl u. Eisen*, 1955, **75**, July 28, 958–974). The author studied the performance of 18 new blast stoves in 9 works (supplied by 6 manufacturers) as well as old ones for comparison and presents a substantial report on constructional details of the stoves investigated, gas- and blast-quantity measurements, temperature measurements, addition of cold blast, gas analysis, pressure measurement, thermal efficiency, thermal load, heat-transfer capacity, and thermal appraisal of the checkers.—T. G.

Mode of Operation and Service Behaviour of Turbo-Blowers. W. Encke. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 452–456). The author discusses the aerodynamical principles of turbo-blowers and shows the characteristics of the various types of blowers, with their main applications in the iron and steel industry.—T. G.

Present State of Development of Large Gas Engines Used for Blower Drives. H. Möhring. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 473–478). The author discusses the advantages of large gas engines compared with steam-turbine blowers and their economic proposition. A gas engine is usually chosen if no boilers are available or if the capacity of the boilers is already used up. Recent improvements in design and performance are outlined.—T. G.

Blast-Furnace Operation. L. N. Collins. (*Tisco*, 1955, **2**, July, 108–119). The operation of a blast-furnace is described in some detail with special reference to blowing-in, the calculation of the burden and method of charging, control of hot blast and stove operation, flushing and casting, control of iron analysis, maintenance, and blowing-out.—L. E. W.

Blast-Furnace By-Products. P. Mehta. (*Tisco*, 1955, **2**, July, 162–169). The author discusses the composition and utilization of blast-furnace gas and the composition and uses of flue dust.—L. E. W.

Expending Blast Furnace Stack Life after Appearance of Hot Spots. R. W. Sundquist. (*Iron Steel Eng.*, 1955, **32**, June, 88–94). Methods of detecting 'hot spots' are reviewed and methods of remedying the trouble are described. Data are given concerning a number of actual hot spots.—M. D. J. B.

The Bessemerizing Process in the Hearth of a Blast-Furnace. K. Kanamori *et al.* (*Rep. Inst. Indust. Sci., Tokyo Univ.*, 1955, **4**, (4), Mar., 152–215). [In Japanese]. A report is given of work, in a small experimental converter, and in blast-furnaces, directed towards the production of high-quality low-S iron from ores of high S content and of iron from ores high in Ni and Cr. The principle employed is the use of inclined tuyeres, directed towards the hearth, which, by the use of O_2, render the hearth active and elevate the temperature to approx. 1600° C. The device permits a degree of control, in that hot blast can be used if the hearth should freeze, and the iron quality can be adjusted by additions if necessary. The thermal efficiency of the process is expected to justify its use.—K. E. J.

Blast-Furnace Reactions. V. G. Paranjpe. (*Tisco*, 1955, **2**, July, 135–146). A schematic representation of the zones of reactions in the blast-furnace is given and then the equilibria and kinetics of the reduction of oxides are discussed. Thermal and chemical efficiencies in relation to Gruner's theorem are dealt with, and the reactions in the bosh and hearth zones and those involved in desulphurization are analysed.—L. E. W.

The Equilibrium between Silicon in Molten Iron, Blast Furnace Slag, and H_2–H_2O Mixed Gas. III. Investigation of the Equilibrium of the Reaction $(SiO_2)_{CaO\text{–}Al_2O_3(Sat.)} + 2H_2 = Si + 2H_2O$. K. Sanbongi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1954, A, **6**, Dec., 605–613). The reaction was measured in temperature range 1550–1600° C for conditions of $3Al_2O_3.2Al_2O_3$, Al_2O_3 or $3CaO.5Al_2O_3$ saturation. Activities of SiO_2 in molten slabs, the equilibrium of Si in molten iron, and the liquidus lines in the presence of molten iron were thence determined.—J. G. W.

Some Observations on the Microexamination of High-Alumina Blast-Furnace Slag. D. R. Dhanbhoora and P. Mehta. (*Tisco*, 1955, **2**, Apr., 52–58). From a microexamination of high-alumina blast-furnace slag and from theoretical considerations, the authors conclude that: (i) impoverishment of the slag mother liquor reduces the desulphurizing capacity of the slag; (ii) the dendritic crystallization well known to metals and alloys is also observed in high-alumina blast-furnace slag; (iii) the primary mineral present in the slag is gehlenite ($2CaO.Al_2O_3.SiO_2$); (iv) the melting range of the slag is 1350–1480° C, and (v) a simple correlation of slag structure with temperature can be made for regular blast-furnace operation.—L. E. W.

Desulphurisation of Pig Iron. A. Ofiok. (*Prace Inst. Ministerstwa Hutnictwa*, 1955, **7**, (2–4), 106–114). [In Polish].

Oxidation Degree, Reduction Degree, and Reducibility of Iron Ore. S. Sasaki and H. Adachi. (*Tetsu to Hagane*, 1955, **41**, Apr., 399–407). [In Japanese]. Methods of indicating the degree of oxidation or reduction of ore are examined, and tests on the factors influencing reducibility are described. With CO and coke, better reducibility was found with small ore sizes, particularly < 1 mm. The highest reduction rate was found with 30% of coke. With CO, reducibility increased with gas flow. An increase of 10% in porosity increased reducibility by 10–13%. With hematite, CO flow rate had a greater effect than ore diameter in the larger sizes.—K. E. J.

The Reduction of Iron Ores Which Contain Titanium. O. Barth. (*Inst. Hierro Acero*, 1955, **8**, Apr.-June, 149–158). [In Spanish]. The titanium-bearing minerals are reviewed and the different methods available for the separation of titanium and iron from them are discussed.—P. S.

The Metallurgical Assessment of Iron Ores and Other Raw Materials. A. N. Pochwisnew. (*Metallurgie*, 1955, **5**, Mar., 82–85). Prof. A. N. Ramm (Leningrad) has suggested that the metallurgical value of ores be expressed in terms of the "thermal equivalent" (i.e. the amount of heat required to smelt 1 kg of a given ore in a blast-furnace under certain conditions). This enables coke consumption to be calculated in advance, consumption statistics to be checked, and prices of the various raw materials to be related to their "thermal equivalents."—L. J. L.

Interaction of Solutes in Liquid and Solid Solution in Iron. E. T. Turkdogan. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 66–73). [This issue.]

TREATMENT AND USE OF SLAGS

Utilization of Slag Cements for Airfields and Road-Making. B. Wentz. (*Silicates Indust.*, 1955, **20**, May, 189–193). [In German]. A survey of the utilization of blast-furnace slag cements in Germany in the past 15 years is made.—P. F.

New Method Expands Slag for Aggregate Use. S. P. Kinney. (*Iron Steel Eng.*, 1955, **32**, June, 127–132). The article describes a new method of expanding slag for use as a light weight aggregate. The process consists of the use of a combination of steam, air, and water. No mechanical parts are required in the process.—M. D. J. B.

Confrontation of Ideas. R. Feron. (*Silicates Indust.*, 1955, **20**, Aug.-Sept., 299–308). Properties, uses, and certain aspects of the technology of slag cements are discussed.—P. F.

DIRECT PROCESSES

Pig Iron and Steel From Low-Grade Ore and Coke. (*Engineering*, 1955, **179**, June 10, 738–739). A brief description is given of the Sturzelberg ironmaking process and also of a method of converting the iron into steel in lance-blown converters.—M. D. J. B.

Sponge Iron. (*Usine Nouvelle*, 1955, **11**, Jan. 27, 65). Sponge-iron production, from a mixture of ore and coal fines, in a special type of rotating furnace, is described. The method is used at Domnarvet, in Sweden.—T. E. D.

PRODUCTION OF STEEL

The Setting Up of a Steel Works at Paz de Rio (Colombia). (*Usine Nouvelle*, 1955, June, 51–53). Construction work by Tissot et Cie. of Bordeaux and engineering by McKee of Cleveland began in 1952. General organization of the project is outlined and descriptions are given of a number of specific operations.—T. E. D.

The Economics of Iron and Steel Production from Inferior Raw Materials. R. Baake. (*Metallurgie*, 1955, **5**, Mar., 77–82). The author's conclusions are that it is far more important to attain a high alumina content in the slag than had been supposed hitherto; that the development of larger low shaft furnaces is more important than the use of oxygen in the furnace; that the bloomery process is expensive, but can be economical if partly carried out in the electric furnace; and that the development of the Bulle oxygen-heated hearth would appear to promise well.—L. J. L.

Air Pollution: Furnace Types and Sizes Dictate Most Effective Controls. N. R. Shaffer and M. A. Brower. (*Iron Age*, 1955, **175**; Apr. 28, 100–102; May 5, 110–112; May 12, 100–102). The authors explain the regulations, methods, equipment, and costs required for air pollution control in Los Angeles County, for steelworks, iron foundries, and non-ferrous foundries. The following methods are described: electrical precipitators, water scrubbers, bag filters, electrical precipitators with humidifiers, etc. The best practice reduces atmospheric contamination by more than 95%.—D. L. C. P.

Karabuk: New Extensions to Turkey's Iron and Steel Works. (*Iron Steel*, 1955, **28**, May 11, 205–207). Brief details are given of the new extensions to the Turkish iron and steel works at Karabuk. The main items are a new 600-ton inactive mixer with crane facilities, and the reconstruction of the original heavy mill.—G. F.

Dephosphorization in a Side-Blown Basic Converter. R. C. Buehl and M. B. Royer. (*U.S. Bur. Mines Rep. Invest.*, 1955, Feb., No. 5102). The results are presented of tests successfully

carried out on a 1-ton side-blown basic converter to dephosphorize iron containing 3% P, 1% Mn, and < 1% C. The technique developed includes preheating and injection of lime through the tuyeres.—B. G. B.

Enquiry into the Stopping of Converters for Repair of the Lining or Change of the Bottom. R. Lanquetin. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (6), 1215–1226). A brief outline is given of a method of stripping the used lining and renewing the walls and bottom.—T. E. D.

Method of Stopping the Converter Operation by Opacimetry. Application to Blowing with Oxygen Enriched Air and Oxygen–Steam Mixtures. Galey. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (6), 1209–1213). The method depends on measuring the opacity of the flame photoelectrically during the removal of phosphorus. Graphs of opacity *v.* time for a normal charge, and showing differences between cold and hot charges, are given. The effect of oxygen enrichment and the addition of steam is also indicated.—T. E. D.

50 ton Converter. Decamps. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (6), 1205–1208). The profile of a 50-ton converter is given. Results of 6 months' working with enriched blast are briefly reported.—T. E. D.

Contribution to the Study of the Role of Manganese in Thomas Converter Refining. P. Leroy. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, (6), 1227–1232). Pig iron of similar composition from three works with about 0·3–0·5% Mn and also pig iron with the Mn content raised to 1–1·3% were blown in the converter. The relations between FeO in the slag and phosphorus in the cast, and between FeO in the slag and residual manganese, are shown graphically. It is concluded that $Mn_{steel} \times (FeO)_{slag} = 2{\cdot}9 \times 10^{-2} Mn_{pig\ iron}$

Reactions Involved in the First-Stage Graphitization of Iron–Carbon–Silicon Alloys. W. S. Owen and J. Wilcock. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 38–43). [This issue.]

PRODUCTION OF FERROALLOYS

U.S. Research on Manganese Ores and Slags. (*Min. J.*, 1955, **244**, May 20, 560–561).

Blast-Furnace Production of Ferromanganese. E. J. Hancock. (*Tisco*, 1955, **2**, July, 154–161). The specifications for steelmaking grades of ferromanganese are given and the raw materials used by T.I.S. Co. are discussed with particular reference to their composition and locality. The principles of burdening and the chemistry and control of chemical composition are outlined. Operational troubles and the handling of products are described and the article concludes with a brief consideration of the future of the ferromanganese industry.—L. E. W.

Silicon and Manganese Reactions in Ferromanganese Blast-Furnace Processes. E. T. Turkdogan. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 74–79). [This issue.]

Mineral Industries of Orissa. N. C. Nandy. (*Tisco*, 1955, **2**, Apr., 76–84). An account is given of the development, occurrence, reserves, and production of the important mineral resources (iron and manganese ores, coal, limestone, dolomite, chromite, graphite, clay, mica, etc.). The prospects for a ferro-alloy industry in the State are discussed.—L. E. W.

Ferromanganese. R. Strubl and O. Sedláček. (*Hutnické Listy*, 1955, **10**, (8), 462–469). [In Czech]. The more important methods of producing low- and medium-carbon ferromanganese are surveyed from the point of view of quality of the product and relative production costs.—P. F.

FOUNDRY PRACTICE

The Chemical Composition of Grey Cast Irons and Their Tensile Strengths. P. A. Heller and H. Jungbluth. (*Giesserei*, 1955, **42**, May 12, 255–257). The relationship between the degree of saturation and the tensile strength has been established by Collaud in his "normal diagram." The validity of this diagram for grey cast iron has been investigated and a critical survey made of appropriate published papers. For a 30-mm test rod the results coincided with those predicted by Collaud. The practical use of the wall-thickness sensitivity law is described.—R. J. W.

The Structure, Mechanical Properties, and Standardisation of Cast Iron in terms of Two Variant Systems. A. Collaud. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, Mar., 65–76; Apr., 105–117; and May, 151–161). The author shows the structure of cast iron to depend on two separate influences, the physical-chemical constitution and the effects of cooling on crystallization. These two influencing systems may be more simply replaced by properties of the cast iron which are exclusively dependent on them. The elastic modulus is a function of the carbon content of the iron and the Brinell hardness illustrates the condition of the crystal structure. An analysis is made of data on the mechanical properties of cast iron and it is shown that the elastic modulus E is directly proportional to the ratio of tensile strength and to Brinell hardness Δ.

$$E = K \cdot \frac{\sigma}{\Delta}$$

It is further shown that the ductility of the metal is a function of σ/Δ^2. Further analysis of the mechanical properties of cast iron shows the tenacity of the metal to be a function of second powers of tensile strength and Brinell hardness. Using this relation and others previously obtained the author obtains diagrams relating the mechanical properties of cast iron with eutectic saturation and specimen diameter. From these a standard diagram is derived relating elastic moduli, tensile strength, and Brinell hardness to specimen diameter. This is intended to be a classification of cast iron which allows the mechanical properties of a given specimen to be deduced without its destruction being involved.—J. R. P.

The Effect of Plastic Deformation on Graphite Particles in Cast Iron. B. Sigg. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, May, 148–150). The work-hardening of cast-iron specimens by plastic deformation was carried out and microsection photographs are shown displaying the proportional elongation of the initially spherical graphite particles.—J. R. P.

The Significance of a Standard of Classification of Cast Iron. J. Foulon. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, Apr., 118–121). The batch analysis of cast-iron products by sampling techniques is described. It is suggested that the tensile strength of the material is an ideal criterion of quality and if this quantity is established as a standard for a bar of given diameter the properties of the metal are further defined by Collaud's classification diagrams.—J. R. P.

The Validity of Collaud's Standard Diagrams. P. A. Heller. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, Mar., 81–82). The diagrams obtained by Collaud for the mechanical properties of cast iron were used to give values for the elastic moduli and tensile strength of specimens of hypereutectoid iron. A comparison of these values with those obtained experimentally showed good agreement supporting the validity of the diagrams.—J. R. P.

Correlation between the Structure and Mechanical Properties of Cast Iron. A. de Sy. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, Mar., 76–80). The tensile strength of cast iron is shown to be the tensile strength of the matrix steel multiplied by a coefficient less than unity due to the presence of graphite in the matrix. The matrix strength for pearlite is double that for ferrite. The coefficient is a function of the quantity of graphite, the shape and dimensions of the particles, and their distribution in the matrix, but the spherical type of graphite particle gives a value of 0·8 and laminar particles 0·4 for the coefficient.—J. R. P.

The Peaceful Application of Atomic Energy, and its Effect on Foundry Practice. S. Wadewitz. (*Giessereitechnik*, 1955, **1**, May, 57–59).

The Manufacture of Ball Pebbles in Iron Moulds. E. Bakovsky. (*Giessereitechnik*, 1955, **1**, Apr., 42–46).

Some Observations on a Cupola Externally Cooled by Flowing Water. (*Fonderie*, 1955, Mar., 4413–4414).

Operation of a Medium-Sized Water-Cooled Cupola. P. Hubert. (*Fonderie*, 1955, Mar., 4414–4422). The modification of a cupola so that it was cooled by a flowing stream of water over the shell is described and the operation of such a cupola is discussed. The heat losses into the cooling water are considered and a heat-balance calculated for the operation of the modified cupola.—B. C. W.

Operation of Water-Cooled Cupolas of 1000 to 1500 mm Internal Diameter. F. Danis. (*Fonderie*, 1955, Mar., 4423–4426).

Progress in the Construction of Recuperators for Hot-Blast Cupolas. A. Schack. (*Giesserei*, 1955, **42**, June 9, 302–307). The advantages of hot-blast melting are first reviewed. The two types of steel recuperator, those with the waste gases around the tubes and those with the waste gases through the tubes, are discussed separately. The maximum wall temperature with both designs of recuperator are compared. Radiation-type or spiral recuperators are described and criticized. A favourable design is one combining a radiation recuperator with one with waste gases going through the tubes.—R. J. W.

Work with Hot-Blast Cupolas. W. Haas. (*Giesserei*, 1955, **42**, May 26, 291–292). As opposed to the cold-blast cupola, the successful operation of a hot-blast cupola entails close supervision of the volume of blast, the blast pressure, and the temperature of the blast; of the waste-gas temperature at the entrance and exit of the blast heater; and of the volume of the coke bed. The operation of hot-blast cupolas is discussed, including the mixtures to be used in the charge. Typical mixtures for both cold- and hot-blast cupolas are tabulated and compared.—R. J. W.

Experimental Melts in the Basic Cupola. P. Holtzhaussen. (*Met. u. Giesserei Techn.*, 1951, **1**, Oct., 310–316). A description is given of operational measures and types of charge required to satisfy the Soviet Bessemer steel standards calling for maxima of 0·09% P and 0·07% S. Soda desulphurization designed for this purpose being time-consuming, experiments were carried out with a basic cupola lining. The required maximum contents were not attained.—L. J. L.

Excess Fixed Carbon in Cast Iron; Its Causes and Reduction or Conversion by Silicon. A. Lincke. (*Met. u. Giesserei Techn.*, 1951, **1**, Sept., 279–281). The author aims to demonstrate that the use of highly concentrated briquettes of Fe–Si alloys is both economical and beneficial for casting.—L. J. L.

The Structure of Grey and White Cast Irons at High Temperatures. L. Bezděk and D. Růžička. (*Slévárenství*, 1955, **3**, (8), 225–233). [In Czech]. A high-temperature microscope was used to study the primary dendritic austenite, the graphite, and the steady decomposition of the structure of grey cast irons. Observations at the temperatures used (1000° C) were facilitated by vacuum-etching the specimens. In white cast irons the changes of the pearlitic structures in austenite and the decomposition of pearlite in individual grains of austenite were studied.—P. F.

Alloying of Cast Iron by Means of Slag in the Cupola. B. Sochor. (*Slévárenství*, 1955, **3**, (6), 169–173). [In Czech]. Titanium and boron were found to pass from slags to the metal in the cupola. The effect is likely to occur also with Ni, Mo, V, Cr, W, and other metals. Thus by using boron- and titanium-rich slags, expensive ferro-alloys can be dispensed with. Both elements were found to decrease slag viscosity.—P. F.

High Strength Irons Without Special Alloying Elements. J. Paxal. (*Mét. Constr. Mécan.*, 1955, **87**, Feb., 95–101; Mar., 173–179; Apr., 277–284; May, 369–375; June, 479–487). The strength of cast irons is reviewed and data concerning their mechanical properties are considered; various forms of intercrystalline fracture are discussed. A detailed review of published techniques for the manufacture of high-strength irons is presented. The influence of chemical composition on the mechanical properties of cast irons is given in graphical form. Processes for the manufacture of these special irons are described. Examples of the preparation of cast irons having a high resistance to shock and with a high resistance to strength by blending of different irons and steels are given.—B. G. B.

REHEATING FURNACES AND SOAKING PITS

Soaking-Pit Practice at the Abbey Works of the Steel Company of Wales Ltd. R. H. Slade. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 3–9). [This issue.]

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Description of Batch and Portable Annealing Furnaces for Coiled Strip. H. B. Helm. (*Iron Steel Eng.*, 1955, **32**, Mar., 73–74).

Continuous Batch Type Annealing Furnace. R. H. Gelder and W. E. Hand. (*Iron Steel Eng.*, 1955, **32**, Feb., 107–111). The authors describe a new type of annealing furnace in operation at Armco Steel Corp. which gives greater production with lower fuel consumption. They claim that the advantages are due to the placement and arrangement of the burners so that the heat input is concentrated at the bottom of the charges and to the precise control of temperatures.—M. D. J. B.

Versatile Wire Annealing Furnace. R. W. Campbell. (*Wire and Wire Prod.*, 1955, **30**, Feb., 188, 214–215). A furnace, developed under an Atomic Ener[illegible] Contract, can bright-anneal continuously six wires in the 1200° C range.

Softening with a Time Dependence of Cold-Drawn Carbon Steel. I. Low Carbon Steel. G. Mima. (*Osaka Univ., Techn. Rep.*, 1954, **4**, Oct., 321–335). Softening of cold-drawn low-carbon steel was studied by metallographic examination and by means of tensile tests. After about 25% reduction in area, the trend of the softening curves for isothermal annealing above 600° C does not change. It was demonstrated that the conventional nucleation and growth mechanism does not account for the annealing process of low-carbon steel.—J. G. W.

Vertical Annealing Furnaces for Metal Strip. F. C. L. Eisenmenger. (*Z. Metallkunde*, 1955, **46**, Apr., 264–268). Advantages of the continuous vertical strip annealing furnace are outlined—rapid and uniform heating, with consequent increase in output.—L. D. H.

Annealing Control Makes the Difference. E. J. Moritz. (*Steel*, 1955, **136**, May 23, 104–105). The annealing of motor and transformer laminations in a continuous roller-hearth furnace is described. Four zones give the required treatment; quality is better than with batch processing and cost similar.

Isothermal Hardening of Cast Iron with Spheroidal Graphite. T. G. Demidova and M. N. Kunyavskiĭ. (*Liteĭnoe Proizvodstvo*, 1955, (2), 20–22). [In Russian]. The investigation described was carried out to see if isothermal hardening is as advantageous for cast iron with spheroidal graphite as for grey iron. The microstructures and micro-hardness of the products of the isothermal decomposition for bath temperatures of 200–750° C were studied, and wear-resistance tests were carried out. The wear resistance of the isothermally hardened iron was found to be considerably higher than that of iron of the same hardness hardened in the ordinary way; 250–350° C is the isothermal hardening temperature recommended for most practical purposes for iron with spheroidal graphite.—S. K.

The Influence of Original Structure of Plain Hypereutectoid Tool Steels on Behaviour During Hardening. T. Brüggemann. (*Met. u. Giesserei Techn.*, 1951, **1**, July, 195–197). Three different hypereutectoid carbon steels whose original structure inhibited pearlite and granular cementite were hardened under identical conditions. The Rockwell C hardness attained was the same in all three, but only such samples of one of the three had cracks whose original structure inhibited lamellar pearlite.—L. J. L.

Uniform Hardness for 410 Stainless Castings. W. B. F. Mackay. (*Precision Met. Mold.*, 1955, **13**, June, 40–41, 88). Details are given of the homogenization, quenching, and tempering treatments carried out on small 13% Cr, 0·15% C steel castings to prevent erratic hardness results.—D. H.

Studies on the Quenching Media, 3rd Report, The Cooling Ability of Oils. M. Tagaya and I. Tamura. (*Osaka Univ., Techn. Rep.*, 1954, **4**, Oct., 305–320). Cooling curves of a number of fatty oils, fatty acids, mineral oils, and of some hydrocarbons were measured and compared, the effects of their composition or chemical characteristics being noted. The difficulties of increasing the cooling ability of mineral oil are discussed.—J. G. W.

FORGING, STAMPING, DRAWING, AND PRESSING

Engine Blades by Garringtons. (*Aeroplane*, 1955, **88**, Mar., 274–278). The techniques used by Garringtons Ltd., for the manufacture of blades for gas turbines are described. High-precision forging methods are used.—B. G. B.

Efficiency of Various Types of Drive in Hydraulic Presses. W. Dohrn. (*Z. Metallkunde*, 1955, **46**, June, 405–415). Energy losses in hydraulic presses are discussed, various types of drive and hydraulic fluids compared, and methods of increasing efficiency outlined, with reference to a 2500-ton press.

Steel for Radially Stressed Heavy Forgings. O. Krifka. (*Steel Processing*, 1954, **40**, Dec., 757–766). The author presents some of the most recent German ideas on the forging and steel-making practices which are most appropriate for special heavy forgings, notably rotors. The pouring procedures, forging, and heat-treatment of several large rotor bodies are discussed, and the test results critically examined. Open hearth and electric furnace practices are discussed with respect to ingot quality.—P. M. C.

The Assessment of Forgeability by the High-Temperature Tensile Test. J. Dauvergne, M. Pélabon, and J. Ivernel. (*Rev. Met.*, 1955, **52**, Feb., 85–93). Low-carbon steels, alloyed or not, sometimes show near 1000° C, owing to a "critical zone of forgeability," little ability to deform. The work described indicates that the nature and content of added deoxidants have a marked effect on the ability to hot-form. The high-temperature tensile test, between 900° and 1200° C, accurately

reveals taps which have a weak forgeability. This test may also be applied to the fabrication and forming of tubes.

Commercial Shearing and Stamping Inc.—A Speciality Job Shop in The Forging Industry. H. E. Trout, jun. (*Steel Processing*, 1955, **41**, Feb., 81–85). A general description with illustrations is given of the plant and class of work undertaken by the Commercial Shearing and Stamping Company of Youngstown at its new Chicago plant. Equipment includes a variety of upsetters from 1½ to 6 in. capacity, forging roll facilities, and a 1600-ton forging press.—P. M. C.

A Discussion of Engineering Considerations of Counter-Blow and Drop Hammers. M. S. Reed. (*Steel Processing*, 1955, **41**, Mar., 157–162). This discussion relates to an article entitled "The Counter Blow Hammer *vs.* Drop Hammer, A Comparison," which appeared in *Steel Processing*, 1954, **40**, Sept. The author discusses at length the distribution of impact energy between workpiece, anvil, and foundation, and the theoretical computation of impact energies and velocities. He raises doubts about many of the arguments and factual statements in the original article.—P. M. C.

Peterson Products Corporation—Difficult Stampings A Specialty. H. E. Trout, jun. (*Steel Processing*, 1955, **41**, Mar., 153–156, 195). A general account with illustrations is given of the plant and type of jobs undertaken by the Peterson Products Corporation of Chicago. A variety of deep-drawn products in ferrous and non-ferrous metals are handled including washer tubs, food containers, refrigerator parts, etc.—P. M. C.

Time Value Predictions for Power Press Operations. J. Evans. (*J.S. African Inst. Mech. Eng.*, 1954, **3**, Feb., 223–233). Time and motion study techniques were used and the effective data, which were synthetically recorded, are presented in three parts. Section *A* of the first part specifies the basic principles and sets out mathematical expressions; section *B* describes the method of application for power press first operation work. Part II deals with second and subsequent power-press operations; basic mechanical and physical work elements are described, mathematical expressions are recorded and final figures tabulated for constant and variable work elements. Part III provides a brief explanation of physical compensating relaxation factors, and sets out examples of actual time value computations for a first and subsequent power press operation.—L. E. W.

Contribution to the Study of the Stamping of Metals. L. Godtschalck. (*Métaux–Corrosion–Indust.*, 1955, **30**, Feb., 47–77; Mar., 110–133; Apr., 155–172). A comprehensive account of metal stamping is presented. Theories of the mechanism of the stamping process are discussed and the stages of deformation from beginning to end of the stamp are explained. The influence of the metal structure on ease of stamping is described and the effect of heterogenous structures in basic-Bessemer mild steel is considered.—B. G. B.

Metal Pressing as a Modern Production Method. (*Flow Turning, Roll Pressing*). R. Vockenberger. (*Maschinenbau Wärmewirtschaft*, 1955, **10**, Aug., 241–248). A description is given of the "flow-forming" process, and examples are given of its application.—L. D. H.

Hydraulic Spinning. (*Aircraft Prod.*, 1955, **17**, July, 282–286). An hydraulic spinning machine made by the Cincinnati Milling Machine Co. is described and illustrated.—T. E. D.

Radial Draw-Forming. (*Aircraft Prod.*, 1955, **17**, July, 255–261). Sheet forming on a Bath-type machine is described. The work piece is held at yield tension and is forced by compression against a rotating die.—T. E. D.

Draw Punch "Flakes" Cause Breakage of Extruded Shells. H. J. Pessl. (*Steel Processing*, 1955, **41**, Feb., 113–114). An unusual cause of material failure during the drawing of 75-mm shell cases is described. Following a high percentage of case fractures during drawing, the draw punch eventually split longitudinally revealing a fatigue fracture (of the punch). It was assumed that during development of this internal fracture, before the punch actually split, the diameter of the punch increased continually. This in turn reduced the wall thickness of the shells and resulted in the abnormally high percentage of case fractures.—P. M. C.

ROLLING-MILL PRACTICE

Multiple-Purpose Hot Rolling Mill. (*Engineer*, 1955, **199**, Apr. 29, 611–612). A new mill designed to meet the exacting requirements of producing a wide range of speciality steel products is described. The mill which incorporates "automation" is installed at the Carpenter Steel Co., U.S.A.

Rolling of Shapes in Alloy and Tool Steel Grades. E. E. Davis and A. H. Highley. (*Iron Steel Eng.*, 1955, **32**, June, 59–64). The paper describes how a shape is processed from the initial customer's enquiry to the rolling mill. Pass design in relation to the type of alloy steel is discussed, and the importance of guides and guide set-ups stressed.—M. D. J. B.

New Merchant Bar Mill Equipped for Maximum Versatility. R. A. Peterson. (*Iron Age*, 1955, **175**, June 9, 85–87). The arrangement of a new merchant bar mill at Phoenix Mfg. Co., Ill., is described. Present output of 45 tons per hour of 3½ in. rounds or 10 tons per hour of ⅜-in. rounds will be improved.

Unique Rolling Mill Has Ingenious Equipment; Rolls Bar Shapes, Strip to Order. R. T. Reinhardt. (*Western Metals*, 1953, **11**, Nov., 66–67). The recent establishment of a small company (Western Rolling Mills, Inc., Calif.) is described. The company is of interest in that it will produce rolled bar, strip, and shapes in much smaller lots than is customary with larger producers.—P. M. C.

Plate Mill Design and Rolling Practice. E. Lynch. (*Iron Steel Eng.*, 1955, **32**, May, 91–95). The Sheffield Steel Corp. mills are described. These consist of a plate mill comprising a 24 × 36 × 116 in., 3-high rougher and a 36 × 54 × 130 in., 4-high finishing mill.—M. D. J. B.

Study on the Weight of Sheets. Jolin. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (5), 1031–1043). Variations of weight in individual sheets and in batches of sheets are determined as a ratio to the theoretical weight corresponding to the nominal thickness. Maximum and minimum tolerances are calculated.—T. E. D.

Production of Steel Strip and Wire in Argentina. (*Tecn. Indust.*, 1955, **23**, May, 570–572). [In Spanish]. Wire and strip for a variety of industrial and agricultural equipment is produced in the new factory of the Acinda Co. in Santa Fe Province.—P. S.

Magona's New Mills Lift Italy's Strip and Tinplate Output. (*Anvil*, 1955, **3**, Spring, 4–7). A description is given of a 16½ in. and 53 in. × 48 in. reversing cold steel strip mill and a 13 in. and 39 in. × 38 in. reversing cold tinplate mill installed by the Davy United group for La Magona d'Italia as part of their expansion programme.—L. D. H.

Best Reel Performance is Obtained When Current Regulator Operates on The Generator. A. J. Winchester. (*Blast Furn. Steel Plant*, 1955, **43**, June, 647–649).

New Developments in Continuous Rolling Mills for Semi-finished Products. L. Wegmann. (*Demag News*, 1954, (138), 1–8). A new continuous rolling mill for semi-finished products built by Demag for a South African steelplant (Iscor) is described.—B. G. B.

Experience with a High-Speed Ardometer in Coiling Hot-Rolled Strip Steel. B. von Sothen and G. Eichert. (*Stahl u. Eisen*, 1955, **75**, Mar. 24, 356–357). The temperature range at which hot-rolled strip steel can be coiled is limited and needs therefore close supervision. The high-speed ardometer measures the surface temperature of the strip and indicates the result within 0·5 s. The surface temperature is measured by a thermocouple and the thermo-electric force fed into a galvanometer. The galvanometer deflects the light from a bulb on to two photocells which operate in opposition. The potential difference of the two photocells is amplified and recorded. Signal lamps for GO and STOP within a predetermined temperature range can be provided.—T. G.

Mill Pays Off in Flexibility. (*Steel*, 1954, **135**, Dec. 6, 124–127). Modern plant at Carpenter Steel Co., Pa., is described. Tool, stainless, and alloy steels are taken as ingots and rolled into strip, coiled rods, and round bars specifically for small orders.—D. L. C. P.

Cold Reduction Facilities at Fairless Works. R. R. Shedd. (*Iron Steel Eng.*, 1955, **32**, May, 55–62). The 21 in. and 53 in. × 48 in. 5-stand tandem mill and the 21 in. and 56 in. × 80 in. 4-stand mill at Fairless are described. These mills have delivery speeds of 7000 and 3100 ft/min respectively, rolling tinplate.—M. D. J. B.

Progress in the Design of Equipment for Cold Rolling. S. Koncewicz. (*Hutnik*, 1955, **22**, (6), 193–199). [In Polish].

Modern Cold Rolling Mills. G. W. Ashton. (*J. Inst. Prod. Eng.*, 1955, **34**, Feb., 111–119, 110). Two modern cold-rolling mills installed at the Shepcote Lane Works of Firth-Vickers Stainless Steels Ltd. are described in detail. One is an orthodox 4-high mill and the other is a Sendzimir mill.

Substitutes for Palm Oil in the Cold Rolling of Steel. W. R. Johnson, J. P. Sheehan, and H. Schwartzbart. (*Blast Furn. Steel Plant*, 1955, **43**, Apr., 415–423). The results of a number of tests carried out on strip mills and in the laboratory to find a substitute for palm oil as a lubricant are reported. A simple wire-drawing test has been developed for testing the efficacy of lubricants. Palm oil and modified tallow are found to be the best lubricants, followed by pure fatty acids, proprietary rolling-mill oils, and petroleum oils.—B. G. B.

Innovations Mark Production of Electric Weld Tubing. (*Iron Steel Eng.*, 1955, **32**, Feb., 138, 141). Innovations introduced into the Electric Weld Tube Division of Jones and Laughlin Steel Corp. include not only technical points but also handling arrangements, dip tanks, and a gas-fired oven which bakes on the paint.—M. D. J. B.

The Modern Continuous Weld Pipe Mill. L. V. Johnson. (*Iron Steel Eng.*, 1955, **32**, Feb., 70–75). This article describes the manufacture of continuous butt weld pipe at the Fairless Works of National Tube Division of United States Steel Corp.—M. D. J. B.

High Capacity Straightener for Tubes and Bars. A. L. Thurman. (*Blast Furn. Steel Plant*, 1955, **43**, Apr., 424–426).

Extra Strength from Same Analysis. (*Steel*, 1955, **136**, Mar. 28, 86–88). A new cold expanding machine for seamless pipe, at the Lorain Works of U.S. Steel Co., is described. A thimble-shaped expander is pushed mechanically through the pipe.—D. L. C. P.

Rolling of Seamless Tubes. F. Wiesner. (*Hutnické Listy*, 1955, **10**, (3), 130–139). [In Czech]. The Mannesmann and allied process of tube rolling are described and the piercing mechanisms analysed. The theories of Gruber, Koks, and others on the piercing process in eccentric rolling are reviewed.

The Application of Magnetic Amplifiers for the High-Speed Control of Rolling-Mill Drives. J. Metzger. (*Stahl u. Eisen*, 1955, **75**, Apr. 21, 479–485). The principal advantage of magnetic amplifiers is that they have no moving parts of which the life is limited, e.g. valves or contacts. The author describes experience gained with magnetic amplifiers in a strip mill. The magnetic amplifier acts so quickly that a frequency of 50 c/s is sufficient for controlling rolling-mill drives.—T. G.

Characteristics of Tandem Mill Drives. R. G. Beadle. (*Iron Steel Eng.*, 1955, **32**, May, 97–102). This paper deals with regulating systems for tandem cold strip mills. Electric drive equipment and the associated regulating systems are described. The relative merits of using a magnetic amplifier with a one generator field in a fairly complex circuit or a combination of magnetic and rotating amplifiers in a simpler circuit are discussed.—M. D. J. B.

The Conveyor—Helper of the Rolling Mill Operator. B. Sládek. (*Hutník*, (Prague), 1955, **5**, (5), 146–149). [In Czech]. A conveyor for the transfer of rolled stock from pass to pass is described.—P. F.

Note on the Calculation of Bloom Shear Stop Blocks. L. Gascuel. (*Acier, Stahl, Steel*, 1955, **20**, Apr., 171–172). The author indicates a practical method of evaluating impact reactions and of determining the dimensions of bloom shear stop blocks to withstand the impact stresses.—M. D. J. B.

Billet Separation By the Shear-Fracture Method. W. C. Tucker. (*Steel Processing*, 1954, **40**, Nov., 695–698, 731). Cold shearing of steel billets into lengths suitable for forging is described. Techniques for assuring square ends by using support platforms, and for accurate control of length and weight of cut blanks by automatic gauging are discussed.

800-Ton Plate Stretching Machine. (*Engineer*, 1955, **199**, Feb. 25, 261–263).

Forming Integral Tubing. (*Metal Ind.*, 1955, **86**, Feb. 11, 105–106). An application of roll bonding is described which enables any pattern of tubing to be formed within a single homogeneous sheet of metal. Two sheets of metal, with the required pattern of passages painted on the inner surface with a stop-weld material, are placed together and hot-rolled. After annealing the non-welded areas are inflated to form the required passages. Allowance is made in the original pattern for elongation in rolling.—P. M. C.

Operation of Magnetic Amplifier Controlled Tandem Mills. J. C. Peth and J. W. Brinks. (*Iron Steel Eng.*, 1955, **32**, June, 69–76). The authors describe the operation of the magnetic amplifier control equipment which is working successfully on Pittsburgh Steel's new tandem mill.—M. D. J. B.

Rotary Straightening of Small Tubing. (*Engineer*, 1955, **199**, Mar. 25, 431–432). A tube rotary straightener is described which feeds tube continuously through a corrective bend or a series of bends which are effective in every axis of the tubing, thus producing the equalized residual stresses necessary to obtain true straightness.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Electrical Plant for the Metal Industries. (*Metallurgia*, 1955, **51**, Mar., 137–144). The activities of the British Thomson-Houston Co., Ltd., the English Electric Co., Ltd., the General Electric Co., Ltd., and the Metropolitan-Vickers Electrical Co., Ltd., in this field during 1954 are reviewed.—B. G. B.

Work Measurement for Maintenance. (*Machinist*, 1955, **99**, Feb. 25, 321–323). By establishing standards of performance, work measurement shows how effectively a firm is using its maintenance personnel, and, by pinning times to jobs, it affords a measure of the total man-hours and hence number of men who should be needed.—M. A. K.

Survey of Smoke Control. R. A. Renwanz and S. E. Specht. (*Steel*, 1954, **135**, Nov. 22, 100, 102, 116; Nov. 29, 76–78). Established and developing applications of electrostatic precipitators in iron and steel plants are dealt with. Modern installations mentioned are for removing dust and fume in gases from hot scarfing machines, O.H. and electric furnaces, sintering machines, and cupolas.—D. L. C. P.

Waste Treatment is Tailored to the Job. (*Steel*, 1954, **135**, Nov. 29, 68–70). Installations for dealing with waste water from 2 plants are described. One deals with water from a jet assembly and machining plant at 300 gal/min, the other with cyanide, chromium, and other waste solutions from a plating plant.—D. L. C. P.

The Traffic of Iron and Steelworks. Locomotive Operating. M. D. J. Brisby and J. H. Turnbull. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 30–37). [This issue].

LUBRICATION

Rationalisation of Oil Purchases: Some Aspects of Cutting Oil Surveys. H. A. Snow. (*Sci. Lubrication*, 1955, **7**, Apr., 14–17). Plant surveys, made with the co-operation of the supplier, can simplify the work of purchasing, storing, distributing, and maintaining lubricants by rationalizing requirements and reducing the grades used to a minimum.—K. E. J.

The Area of Real Contact and the Shear Strength of Monomolecular Layers of a Boundary Lubricant. Anita I. Bailey and J. S. Courtney-Pratt. (*Proc. Roy. Soc.*, 1955, **A**, **227**, Feb. 8, 500–515). A technique using cleaved mica allows molecularly smooth surfaces to be placed together and the contact area measured. The force required to shear an applied monomolecular layer of calcium stearate was considerable; this explains why single molecular layers of soap or fatty acids on metals reduce the frictional force by only a factor of 10 but the wear by a factor of approx. 10,000.—K. E. J.

Cementation with Sulphur to Give Self-Lubricating High Wear-Resistant Surfaces. J. Vidal Sanllehi. (*Acero Energ.*, 1955, **12**, Jan.-Feb., 45–49). [In Spanish]. Surface treatment by the "Sulf-Inug" process is described together with the factors which control its industrial application; typical applications are quoted, and it is pointed out that iron, steel, and copper alloys may be advantageously treated with sulphur.—P. S.

Considerations of Phenomena occurring during the Friction of Solid Surfaces. G. H. Göffner. (*Draht, German ed.*, 1955, **6**, May, 172–177). Fundamental concepts of solid friction, as they appear in modern theories, are outlined by reference to the work of the Bowden school on dry friction, Vogelpohl's theory of thin film lubrication, and the connection between friction and wear.—J. G. W.

Multi-Purpose Grease Simplifies Furnace Equipment Lubrication. H. B. Jenkins. (*Iron Age*, 1955, **175**, Feb. 10, 104–105). The use of a new lithium-base grease (Alvania EP) for lubricating blast-furnace equipment at Detroit Steel Co. is described.—D. L. C. P.

Research Points Way to New Methods of Preventing Galling and Seizing. E. S. Machlin. (*Iron Age*, 1955, **175**, Feb. 10, 91–93; Feb. 17, 104–106). A study of several sets of metal pairs to elucidate the behaviour of their surfaces in relative motion is presented, with special reference to titanium. Measurements of friction and weldability were made and the effect of surface films and temperature studied.—D. L. C. P.

New Apparatus for the Measurement of the Stability of Lubricating Oils. B. Blouri. (*Chim. et Ind.*, 1954, **72**, Dec., 1169–1174). The changes in the lubricating properties of oils which occur by ageing are reviewed and a new apparatus for simulating ageing is described.—B. G. B.

Lubricant Code Ends Confusion. D. P. Thomas. (*Steel*, 1955, **136**, Jan. 17, 78, 80). A code system for lubricants in a steel mill is described.—D. L. C. P.

WELDING AND FLAME CUTTING

Seam Welding Low-Carbon Steel. M. L. Begeman and G. C. Walker. (*Welding J.*, 1955, **34**, Mar., 123s–131s). The fabrication of pressure-tight lap joints made with low-carbon sheet steel is discussed. The highest speed for interrupted current welding of each of the thicknesses investigated give welds with essentially zero nugget overlap.—U. E.

The Macro Etch System of Evaluating Quality of Resistance Welding. D. O. Samuelson and F. G. Harkins. (*Welding J.*, 1955, **34**, Feb., 105–111). Nugget size, shape, and internal quality, as examined by macro-etch, are shown to provide all the necessary information to analyse completely the joint for production acceptance.—U. E.

New Techniques in Inert-Gas-Shielded Metal-Arc Welding. R. W. Tuthill. (*Welding J.*, 1955, **34**, Feb., 137–141). The use of CO_2 gas as a protective atmosphere for gas-shielded consumable electrode welding of mild steel is described. The method was developed by the Ford Motor Co., Detroit, and the General Electric Welding Department in York, Pa. High current density and short arc length are used to control spatter with 100% CO_2. Completely porosity-free welds on the poorest rimmed steels are not yet possible, but satisfactory results can be obtained with semikilled steels and correct welding techniques.—U. E.

Direct Explosion Tests of Welding Procedures in Ship Plate. G. S. Mikhalapov and W. A. Snelling. (*Welding J.*, 1955, **34**, Feb., 97s–104s). Semi-killed *ABS* class *B* and rimmed *ABS* class *A* steel (1 in. thick) was subjected to direct explosion tests to determine the effect of low hydrogen weld deposits. The performance of unwelded semi-killed steel plate rolled from the same heat of steel appears to vary widely. The effect of thermal stress relief at 1150° F was found to be beneficial to welds made with E6010 electrodes on the poor performing portion of the heat of semi-killed steel. The performance of prime rimmed steel $\frac{3}{4}$ in. thick was very much inferior to that of $\frac{3}{4}$-in. semikilled steel at all temperatures from 32° F down, but comparable with that of 1-in. thick semi-killed steel.—U. E.

Welding Type 347 Stainless Steel for 1100° F Turbine Operation. R. M. Curran and A. W. Rankin. (*Welding J.*, 1955, **34**, Mar., 205–213). Sound welds could be produced in type 347 stainless steel using an electrode with a ferritic content. The resistance to embrittlement was appreciably increased with a 1925° F post-weld heat-treatment. Highly restrained austenitic welds were successfully heat-treated in the range 1900–2000° F provided a rapid heating rate was used.

Practical Hard Facing with Fused Self-fluxing Metallized Coatings. H. S. Miller. (*Welding J.*, 1955, **34**, Mar., 214–219). The preparation of the surface, spraying of the deposit, fusing of the deposit, and finishing are discussed.—U. E.

Metallic Rectifiers for Arc Welders. G. K. Willecke. (*Welding J.*, 1955, **34**, Mar., 231–236).

Selection of D.-C. Arc Welding Power Sources. A. V. Welch. (*Welding J.*, 1955, **34**, Mar., 241–245). D.C. arc-welding power sources are discussed and it is shown that transient currents and voltages have a controlling influence on usability of the welder in hand metal-arc welding.—U. E.

Fatigue Strength of Butt Welds in Structural Steels. L. A. Harris, G. E. Nordmark, and N. M. Newmark. (*Welding J.*, 1955, **34**, Feb., 83s–96s). Fatigue tests have been conducted of full-scale butt welds in carbon-steel plates with the stress applied either parallel to or perpendicular to the direction of welding. The welds were deposited with E7016 low-hydrogen or E6010 high-cellulose electrodes. There was no significant difference in fatigue strength of welds made with the two types of electrode and tested with the reinforcement on or off for the specimens tested with the stress perpendicular to the direction of welding. For the specimens tested with the stress parallel to the direction of welding, the scatter is large, but E7016 welds with reinforcement either on or off are generally more resistant to repeated loadings than E6010 welds.—U. E.

Developments in the Flame-Cutting of Ship Plate. R. R. Sillifant. (*Welding Metal Fab.*, 1955, **23**, Feb., 40–47; Mar., 88–94). The flame cutting of ship plate is discussed. On the basis of tests carried out under shipyard conditions, the oxy-plane machine developed by the British Oxygen Company, can be used and sited in the flow of material in such a way as to reduce handling time. The advantages of an integrated roller-track system for plate movement are discussed and various improvements in nozzles and gas equipment are described.

Significance of Recent Resistance Welding Research. J. E. Roberts. (*Welding Metal Fab.*, 1955, **23**, Feb., 64–69, Mar., 97–102). The resistance welding research as carried out by the British Welding Research Association has been reviewed. Four major lines of research work are discussed—spot welding of low-carbon steel, projection welding of low-carbon steel, spot welding of light alloys for aircraft construction, and the fundamentals of resistance welding.—U. E.

High Nickel Overlays on Ferrous Metals. G. R. Pease, H. B. Bott, and H. C. Waugh. (*Welding J.*, 1955, **34**, Jan., 40–48). The properties of high nickel alloy overlay welds may be adversely influenced, if diluted with large amounts of ferrous metal unless the ill effects are anticipated and proper precautions are taken. Optimum welding conditions are defined and illustrative properties shown for Monel, "K" Monel, nickel, and Inconel overlays on mild steel, deposited with flux-coated electrodes and by inert-gas methods. The problems associated with obtaining satisfactory overlays on cast iron are also briefly discussed.—U. E.

Calculated Preheat Temperatures to Prevent Hard-Zone Cracking in Low-Alloy Steels. C. L. M. Cottrell and B. J. Bradstreet. (*Brit. Welding J.*, 1955, **2**, July, 310–312). Tables are given which enable a designer to read off the preheat temperature required for the metal-arc welding of a low-alloy steel from the dimensions and form of the joint, the weld size, and the weldability of the steel.—U. E.

A Method for Calculating the Effect of Preheat on Weldability. C. L. M. Cottrell and B. J. Bradstreet. (*Brit. Welding J.*, 1955, **2**, July, 305–309). An empirical equation relating the cooling rate at 300° C in the weld heat-affected zone to the geometry of the joint, the size of the weld, and the initial plate temperature has been derived from experimental data. The equation applies to metal-arc welds on mild and low-alloy steels. The cooling rate which is critical with respect to hard-zone cracking has been found to vary with initial plate temperature. The preheat temperature required to prevent hard-zone cracking when a given electrode is used to weld any joint in a given steel can now be calculated.—U. E.

Hardfacing with the Oxy-Acetylene Flame. E. Ryalls. (*Brit. Welding J.*, 1955, **2**, July, 298).

Strains in Flanged Pipes. Comparison of 'Built-up' and 'Solid' Flanged Pipes under Bolt Loading Conditions. J. Y. Davies and E. J. Heeley. (*Brit. Welding J.*, 1955, **2**, July, 293–297).

The Composition of Weld Metal. W. P. Van Den Blink. (*Brit. Welding J.*, 1955, **2**, July, 285–292). A survey is given of the metallurgical factors that influence the composition of weld metal, with special reference to mild-steel weld metal deposited by covered electrodes.—U. E.

Considerations in the Evaluation of Graphitization in Piping Systems. H. Thielsch, E. M. Phillips, and E. R. Jerome. (*Welding J.*, 1955, **34**, June, 286s–294s). Laboratory investigations are discussed which deal with graphitized piping, sampling, bend and impact testing, metallographic examinations, and effects of heat-treatments on graphitization. It is shown that periodic weld-probe sampling of carbon and carbon–molybdenum steel piping systems in service at temperatures exceeding 800° F should eliminate hazardous conditions due to graphitization. The elimination of significant degrees of graphitization, or the absence of graphitization, does not ensure that a high-temperature, high-pressure piping system is safe.—U. E.

A Mathematical Analysis of the Temperature Distribution during Flash Welding. E. F. Nippes, W. F. Savage, H. Suzuki, and W. H. Chang. (*Welding J.*, 1955, **34**, June, 271s–285s). The effect of flashing variables, such as material constants, specimen size, rate of platen movement and initial clamping distance, on the stabilized temperature distribution is discussed. Methods are proposed for choosing an adequate mean value of thermal diffusivity for a given material and for evaluating the amount of critical burn-off necessary to establish the stabilized temperature distribution.—U. E.

Inert Gas Welding of Stator Packs. F. J. Pilia. (*Welding J.*, 1955, **34**, June, 559–567).

Design and Application of Edge-Ring Projection Welding. C. A. Czohara. (*Welding J.*, 1955, **34**, June, 551–558).

The Inert-Gas Metal-Arc Overlay Process. C. R. Felmley. (*Welding J.*, 1955, **34**, June, 542–550). An investigation was made of the welding variables which affect the penetration and dilution of overlays deposited by the inert-gas metal-arc-welding process with a consumable electrode.—U. E.

How to Use Semiautomatic Submerged Arc Welding. R. A. Wilson. (*Welding J.*, 1955, **34**, June, 535–541).

Resistance Welding of Stabilized Stainless Steel Strip. E. J. Keefe and D. R. Nash. (*Welding Metal Fab.*, 1955, **23**, Aug., 289–294). An investigation was carried out on resistance welding of austenitic 18/8 Cr–Ni steel strip. The mechanical properties were determined and macrographs show spot welds in titanium-stabilized, high-columbium, and low-columbium stabilized stainless steel. There is a marked difference in macrostructure between titanium- and columbium-stabilized welds, favourable to the titanium-stabilized stainless steel.

Automatic Control of Machine Arc Welding. F. Hirschmann. (*Welding Metal Fab.*, 1955, **23**, July, 262–264). A new equipment for arc length control is described. The equipment, which is non-electronic, makes the welding torch follow the profile of the workpiece; it also moves the torch towards the workpiece and away from it, at the start and end of the weld.—U. E.

The Economic Application of Automatic Arc Welding Equipment. J. A. Lucey (*Welding Metal Fab.*, 1955, **23**, July, 251–257). The article outlines arc welding methods which must be employed to secure the maximum economies with automatic welding.—U. E.

Arc-Welding Costs. Proposals for Proving New Methods of Measurement. A. G. Thompson. (*Brit. Welding J.*, 1955, **2**, Aug., 350–357).

Tests on Forked Tubes used in Boiler Construction. H. Sebulke. (*BWK*, 1955, **7**, June, 256–257).

Flame Cutting with Electronic and Magnetic Tracers. R. J. Helmkamp. (*Steel Processing*, 1954, **40**, Dec., 786–792). A thorough description is given of electronically and magnetically operated tracing devices designed to follow templates of workpieces to be reproduced in plate by gas cutting torches.—P. M. C.

Inspection and Testing of Welds in Ships and Pressure Vessels. B. P. Fielden and E. B. Suters. (*Australasian Eng.*, 1955, Feb. 7, 65–75).

Resistance Welding of High Temperature Alloys. P. M. Howard and D. Wilcox. (*Canad. Metals*, 1955, **18**, June, 58–62).

Welding Cracks in Columbium-Bearing Stainless Steel. (*Metal Progress*, 1955, **67**, May, 109–111). Experiences which led to the modification of the composition of welding rods and base metal of this type of steel are described. These steels are very useful where freedom from intergranular corrosion is essential, but previously suffered from cracks during welding.

The Problem of Weldability in Resistance Welding. C. Penche Felgueroso. (*Cienc. Tecn. Solda.*, 1955, **5**, Mar.-Apr.). [In Spanish]. This paper constitutes a general discussion of the difficulties experienced in the production of satisfactory welds, by resistance-welding methods, in some metals and alloys. Hard zone formation in alloy steel welds is described and techniques for avoiding it are discussed. Problems which affect the successful resistance welding of titanium, aluminium, magnesium, and non-ferrous metals and alloys are also described.—P. S.

Significance of Weldability and a Proposal on its Analytic Expression. M. Okada. (*Osaka Univ. Techn. Rep.*, 1954, **4**, Oct., 357–363). The significance of the term 'weldability' is examined and five different kinds of weldability are proposed together with suitable tests.—J. G. W.

Temperature Distribution during Spot Welding. S. Ito and K. Honda. (*J. Mech. Lab.*, 1955, **9**, Jan., 20–25). The temperature distribution during spot welding is analysed theoretically, whence formulæ for various stages of the process are derived.—J. G. W.

A Study on Low-temperature Brazing. II. Wettability by Droplet Method and Brazing Strength. H. Ishida and S. Yaji. (*J. Mech. Lab.*, 1955, **9**, Jan., 30–35). The contact angle of droplets of various solders deposited on mild steel were measured and correlated with joint clearance and strength. It was found that the greater the wettability of a solder, the faster the alloying and the higher the strength over a wide range of joint clearance.—J. G. W.

Ferrous Welding Metallurgy. With Special Reference to the Welding of Cold-Bent Steel. H. O'Neill. (*Brit. Welding J.*, 1955, **2**, June, 241–246). The welding of steels and of S.G. cast iron is reviewed, reference being made to grain size effects. The principles underlying the selection of elements for high-tensile weldable steels are discussed. Details are given of strain ageing and cracking effects in the welding of cold bent steels.—U. E.

Arc Striking with Argon–Hydrogen Mixtures in the Argon-Arc Process. D. R. Milner. (*Brit. Welding J.*, 1955, **2**, June, 246). A method has been developed in which the hydrogen is switched into the gas stream by means of an electromagnetic valve, after the arc had been struck in argon.—U. E.

Welded Tee Connections. A. G. Barkow and R. A. Huseby. (*Weld. Res. Council, Weld. Res. Council Bull. Series*, 1955, (22), May).

High-Strength, Butt-Brazed Joints. O. T. Barnett and N. Bredzo. (*Steel*, 1955, **136**, May 23, 114, 117). Joints with tensile strengths up to 84,000 lb/in² can be made by the technique mentioned. Butting surfaces are precision-ground and polished, and the joints made extremely thin using pure-silver filler metal.—D. L. C. P.

Transition Temperature of Brittleness, Criterion of Quality of Arc-Welding Electrodes. D. Séférian and M. Moneyron. (*Rev. Mét.*, 1955, **52**, Mar., 219–236). Experiments carried out to determine the quality of arc-welding electrodes from the transition temperature of brittleness are described. The point of inflexion of the temperature/resilience curve gives this temperature. Electrodes with a basic coating had a transition temperature lower than those with an acid coating.

Welding Electrodes for Welding Unalloyed and Low-alloy Steels. A. Schmidt. (*Schweisstechn.*, 1955, **9**, Apr., 37–39). The chemical composition and mechanical properties of a number of Austrian welding electrodes are given and compared with the composition and properties of those given in DIN Standards No. 1913.—U. E.

CORRIGENDUM

In the October *Journal*, p. 182, right-hand column, an inaccurate reference was given to the article **"The Manufacture of Steel Chain Cable"**; it should read "*Machinery*, 1954, **85**, Dec. 3, 1189–1192."

CLEANING AND PICKLING

Suction Plants in the Metal-working Industry. H. Mürmann. (*Metall*, 1955, **9**, Apr., 278–282). Some suction installations for the extraction of fumes and vapours present in metal treatment are described, and component design, choice of materials of construction, as well as heating and ventilation of shops containing suction plant, are discussed.—J. G. W.

The Drying of Strip. D. Hartmann. (*Metall*, 1955, **9**, Apr., 267–271). Formulæ for the design of drying installations for strip and sheet are deduced theoretically, and checked experimentally for brass strip.—J. G. W.

The Regeneration of Derusting Solutions. T. R. Manley. (*Chem. Indust.*, 1955, June 4, 657–658). The author describes briefly the development of a method of regenerating derusting solutions, based on phosphoric acid, using selectively permeable ion-exchange resin membranes.—E. E. W.

Some Industrial Applications of Metal Cleaning. E. L. Streatfield. (*Chem. Indust.*, 1955, July 9, 855–861). The mechanism of degreasing processes is explained. Types of cleaning agents, the general design of plants, and practical procedures are described. Ultrasonic cleaning is also mentioned. Various chemical methods of descaling and derusting are discussed, including pickling by acids and the use of tannins. Electrochemical methods are mentioned.—E. E. W.

Modern Barrel Finishing. (*Mech. World*, 1954, **134**, 546–547). The technique of abrasive barrel finishing is described, attention being given to the effect of abrasive size and shape, the work load height, and the speed of rotation on the rate of material removal.—D. H.

A New Method of Dust Removal for Pendulum Grinders. O. Přáda. (*Hutník*, (*Prague*), 1955, **5**, (4), 103–105). [In Czech]. Possibilities of adequate ventilation in the pendulum

grinding shop are reviewed, and the prototype of a suction arrangement is described. Its introduction resulted in halving the dust content in the shop air.—P. F.

A Modern Plant for the Surface Treatment of Nickel and Stainless Steels. (*Mét. Constr. Mécan.*, 1955, **87**, May, 425–433). A description of this pickling plant of Gilby–Fodor, France, for handling special steels is given. Strip, wire, and tubes are treated in acid and alkaline solutions.—B. G. B.

Sodium Hydride Descaling. D. J. Fishlock. (*Product Finishing*, 1955, **8**, Mar., 59–62).

Servo Control in the Electropolishing of Wire and Strip. A. Korbelak and C. M. Rively. (*Plating*, 1954, **41**, Dec., 1446–1449). An electronic system is described for controlling the electropolishing of tungsten wire of 0·0005–0·005 in. dia. according to variations in wire diameter. The method is suggested to be of general application to control of electropolishing of wire and narrow strip in other metals.—A. D. H.

The Chemical Polishing of Mild Steel by Hydrogen Peroxide—Oxalic Acid Mixtures. A. Hickling and A. J. Rostron. (*Trans. Inst. Metal Finishing*, 1955, **32**, Advance Copy No. 7). Measurements of potential, weight loss, and surface finish were made during the immersion of mild steel in hydrogen-peroxide–oxalic-acid mixtures. Polishing was found to occur when the metal alternates between active and passive states. A proposed theory of the polishing action is proposed and is extended to the general problem of chemical polishing.

PROTECTIVE COATINGS

The Interaction of Oxygen with Clean Metal Surfaces. M. A. H. Lanyon and B. M. W. Trapnell. (*Proc. Roy. Soc.*, 1955, **A**, **227**, Jan. 20, 387–399). Isobars for the adsorption of O_2, H_2, and CO on evaporated films of several metals have been drawn up. At low temperatures many metals exhibit monolayer formation (one adsorbed atom per surface atom); with Fe, hydrogen forms a monolayer, CO a layer intermediate between single- and two-site adsorption, and oxygen several layers of oxide. A rate expression for slow oxygen uptake is derived, which is interpreted in terms of the theory of Cabrera and Mott; up to ten oxide layers are observed.

Notes on Electroplating Metallized Surfaces. S. Wein. (*Products Finishing*, 1955, **19**, Feb., 24–26, 28, 32, 34, 36). The composition of baths for electro- or chemical of Cu, Ag, Fe, Ni, and Au on thin films is given.—A. D. H.

High-Production Line Deposits Quality Chrome Plate on Bumpers. H. Chase. (*Iron Age*, 1955, **175**, Mar. 3, 115–118). The Cu–Ni–Cr plating line in a new Oldsmobile plant, Mich., is described. It is completely mechanized and automatic, but flexible in operation.—D. L. C. P.

Chromium Diffusion Defeats—Corrosion, Heat, Wear. J. Hollingum. (*Machinist*, 1955, **99**, Mar. 4, 361–367). The diffusion of chromium into the surface of steel and other metals by Diffusion Alloys Ltd. has introduced new possibilities for an economical method of treatment for corrosion, heat, and wear resistance.—M. A. K.

Nickel Plating Without Current. S. W. Baker. (*Steel*, 1955, **136**, Jan. 10, 66–67). A description of the ' Alcoplate ' method of chemical nickel plating is given; it is an adaptation of the ' Kanigen ' process. Plating takes place by catalytic reduction of nickel by sodium hypophosphite at elevated temperature. Several advantages are found, and an even, dense, tough nickel coating can be obtained, even on intricate surfaces, on many materials.—D. L. C. P.

The Electrodeposition of Iron–Zinc Alloys. S. Jepson, S. Meecham, and F. W. Salt. (*Trans. Inst. Metal Finishing*, 1955, **32**, Advance Copy No. 4). Methods are given for the deposition of iron–zinc alloys (3–90% Zn) from sulphate and chloride baths.—A. D. H.

Bend Around Galvanizing Embrittlement. R. W. Sandelin. (*Steel*, 1954, **135**, Nov. 22, 92–94). Results and conclusions are reported of an investigation into the cause of galvanizing embrittlement in cold-worked steel. Severe cold work is the cause of embrittlement after galvanizing; hydrogen is only a minor factor. Remedies are adequate bending radii, hot fabrication, annealing, use of aluminium- or other non-ageing steel.—D. L. C. P.

Tin Plating with Potassium Salts. F. A. Lowenheim. (*Tin and its Uses*, 1955, Apr., 7–10). The advantages of using potassium stannate instead of the sodium salt as electrolyte in tin plating are described. The bath is more soluble and more stable; much higher tin concentrations and greatly increased current densities can be used. Bath composition recommendations are given, and the advantages of tin anodes containing about 1% Al in permitting higher anode current densities are indicated.—L. D. H.

Corrosion Tests of Tin–Cadmium Coatings on Steel. S. C. Britton and R. W. de Vere Stacpoole. (*Trans. Inst. Metal Finishing*, 1955, **32**, Advance Copy No. 6). Laboratory and outdoor corrosion tests were carried out on mild steel coated with a layered electrodeposit of cadmium and tin, Sn–75% Cd, Sn–50% Cd alloys, cadmium, tin, zinc, and a tin–zinc alloy. In the salt spray test the alloys retained their ability to protect steel longer than Cd coatings. Although on marine exposure the alloy coatings were similar to Cd in their protection, inland exposure showed that they were inferior. The alloy coatings were resistant to organic vapours given off by insulating materials.—A. D. H.

The Throwing Power of Tin and Tin Alloy Plating Solutions. F. A. Lowenheim. (*Plating*, 1954, **41**, Dec., 1440–1445). Methods of measuring throwing power and covering power are critically reviewed. A rough test consisting of a glass jar with an anode at one side and two weighed cathodes directly behind each other at distances from the anode in the ratio of 1 : 3 was used to determine the throwing power of potassium and sodium stannate baths and the tin–nickel bath. The apparatus was calibrated by means of solutions of known throwing powers. The tin–nickel bath was found to have very high throwing power.—A. D. H.

Clad and Precoated Metals. J. B. Campbell. (*Mat. Methods*, 1954, **40**, Dec., 113–128). Metal laminates in many forms, in which the second layer may be a different metal or an organic one, are now widely used to obtain corrosion resistance, special heat transfer characteristics, expansion properties, and other unusual requirements.—P. M. C.

Epoxide Resins in Metal Finishing. R. N. Wheeler. (*Trans. Inst. Metal Finishing*, 1954, **30**, 273–288). The manufacture and application of epoxide resins (' Epikote ') is discussed. The materials have excellent chemical resistance and are used as primers, as an external size coat on food cans, etc.

Pretreatment Improves Finish Quality. G. C. Close. (*Products Finishing*, 1955, **19**, Apr., 44–47, 50–52). General descriptions are given of the application of phosphating and other chemical treatments as a basis for paints.—A. D. H.

Spraying Methods for Vitreous Enamel. (1) Spray Guns and Machines. (2) Spraying Equipment. (3) Spraying Techniques. J. J. Baker, R. D. Beck, and M. L. Pouilly. (*Product Finishing*, 1955, **8**, Jan., 61–64; Feb., 61–67; May, 65–73, 102).

Evaluation of Etch Primers in Metal Coating Systems. (*Products Finishing*, 1955, **19**, Mar., 42–54). Corrosion tests in humid atmospheres at 160° F on mild steel indicated that blistering of enamel was avoided when an etch primer was used. The surface must be chemically clean; rust and scale must be rigorously excluded.—A. D. H.

Diffusion Chromizing of Steel. E. Gasior. (*Prace Inst. Ministerstwa Hutnictwa*, 1955, **7**, (1), 1–10). [In Polish]. The development of a chromium protective coating of steel and chromizing methods used in the industry are reviewed. Theoretical aspects of chromizing and principal properties of protective coatings obtained by the diffusion of chromium are discussed. Experimental results of chromizing mild steel by annealing in a mixture of chromium, corundum, and ammonium chloride are described. The influence of time and temperature of chromizing on the thickness of the diffused layer and sintering and the adherence of the chromium corundum mixture to the surface of steel were investigated. The behaviour of chromium-coated steel specimens in laboratory corrosion tests comprising salt spray, sulphur dioxide, and nitric and sulphuric acid was tested. The resistance of chromized steel to oxidation at 900° C was also examined.

Chrome Plating for the Small Shop. J. B. Mohler. (*Metal-working Prod.*, 1955, **99**, Apr. 15, 677–679).

Design Specifications for Chromium Plating Thickness. J. B. Mohler. (*Machine Design*, 1955, **27**, Mar., 161–164). In addition to its decorative uses, chromium has extremely useful qualities in engineering fields owing to its resistance to wear because of its hardness and its low coefficient of friction. The article describes methods used and gives data about thicknesses of electro-deposited chromium for various machined parts.—M. A. K.

Hard Chromium Plating Salvages Critical Items; Increases Wearing Power. (*Western Metals*, 1953, **11**, Apr., 53–54). The wide range of hard chromium plating undertaken by the Superchrome Engineering Co. of Los Angeles is briefly outlined.

Recent Developments in Chromium Plating. H. Silman. (*Trans. Inst. Metal Finishing*, 1955, **32**, 33–44). Current practice is reviewed and the following topics are discussed: catalysts containing fluorine, the S.R.H.S. bath, the sodium tetrachromate bath, barrel plating, and tampon plating for applying localized deposits.—A. D. H.

The Effect of Chromium Plating on the Fatigue Strength of Steel. C. Williams and R. A. F. Hammond. (*Trans. Inst. Met. Finishing*, 1955, **32**, Advance Copy No. 1). The effect of chromium plating in reducing fatigue limit of En 25 Ni–Cr–Mo steel has been confirmed. Heat-treatment at 300° C causes a further reduction while annealing at 440° C is beneficial. Measurements of internal stress in the chromium deposits indicate that changes in the fatigue limit are a function of the nature and amount of the internal stress and of the inherent fatigue strength of the chromium plating.

Nickel Plating by Chemical Reduction. W. J. Crehan. (*Product Eng.*, 1955, **26**, July, 148–152). The chemical reduction process for nickel plating enables a very even thickness of plating to be obtained, even when complex shapes are involved. The base materials suitable for plating are discussed, and the importance of correct surface preparation is emphasized. The corrosion properties of a treated specimen are compared for a number of different corrosive atmospheres. A flow diagram for a typical plating system is included.

Practical Bright Nickel Plating. T. E. Such. (*Trans. Inst. Metal Finishing*, 1955, **32**, 45–64).

A Correlation of Metallurgical Hardness and Buffability. H. Faint and R. S. Modjeska. (*Plating*, 1954, **41**, Dec., 1422–1426). An exploratory survey was carried out to assess whether the ease of buffing commercial Ni deposits varies with the Eberbach microhardness. The results were conflicting and indicate that more systematic work is needed in this field.—A. D. H.

A Large-Scale Electroless Nickel Custom Plating Shop. G. Gutzeit and R. W. Landon. (*Plating*, 1954, **41**, Dec., 1416–1421). A description of the Kamgen process of the General American Transportation Co. is given.—A. D. H.

Considerations on Chemical Nickel Plating Methods. R. Studler. (*Corrosion et Anti-corrosion*, 1955, **3**, Mar.-Apr., 92–98).

Tests Regarding the Quality of Galvanised Coatings. H. J. Wiester and D. Horstmann. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein Westfalen.* No. 87, 1954). Tests show that the attack of liquid zinc on iron gives a parabola below 490° and above 520° C; between these temperatures, a straight-line relation holds good. The causes and cures for faulty coatings are discussed. The formation of globules is caused by oxide residues on the iron surface.

Galvanizing Plant for Tubes. J. Leutbecher. (*Stahl u. Eisen*, 1955, **75**, June 16, 777–779). The author describes a modern dry-galvanizing plant for tubes. The throughput varies between 4·8 tons/h for ½-in. o.d. tubes and 10 tons/h for 2-in. tubes.—T. G.

Hot-Dip Galvanizing is a Science. I. W. G. Imhoff. (*Wire and Wire Products*, 1955, **30**, Feb., 167–170, 233–235; Mar., 295–297; Apr., 437–439, 487–490; May, 553–556, 605; June, 681–683, 726–727; July, 787–791, 817–819). Modern methods of hot-dip galvanizing are reviewed, with particular stress on control of the process. Experiments are quoted linking bath temperature and coat weight and this is related to economic aspects of particular applications. The effects of sheet thickness and immersion time on coating thickness are studied both in the laboratory and on the plant, as is the effect of pickling time. Laboratory tests show that optimum speed of removal of sheet from bath is 3 ft/min for the specimens examined. This avoids both drag-out and alloying action. Finally, common faults in practice are catalogued with their causes and remedies.—J. G. W.

Some Mechanical Properties of Flame-sprayed Zinc Layers. E. Gebhardt and H. D. Seghezzi. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, May, 162–164). An examination of some mechanical properties of zinc layers produced by flame sprayers using wire or powder was made. Tensile strength and hardness showed the wire sprayer to be better than the powder sprayer for neutral flames. Oxygen-enrichment of the flame had an adverse effect on the zinc layer from wire but little effect on the layer produced by a powder sprayer.—J. R. P.

Tin–Zinc Alloy Plating. A Corrosion-Resistant Coating for Steel Components. (*Automobile Eng.*, 1955, **45**, Feb., 75–77). A technique for electrodepositing tin–zinc coatings (patented by the Tin Research Institute) is described in detail. A 25% zinc alloy provides best corrosion resistance, and is deposited from a sodium-stannate–zinc-cyanide solution.—P. M. C.

Electroplating with Tin Alloys. J. W. Cuthbertson. (*Schweiz. Arch. Wiss. Techn.*, 1954, **20**, May, 148–152). The necessary conditions for the successful simultaneous electrodeposition of tin and other metals, based largely on the work of the Tin Research Institute, are discussed. The following alloys have been successfully deposited, and details of the plating solutions are given: 75% Sn, 25% Zn; 10% Sn, 90% Cu (red bronze); 43% Sn, 57% Cu (speculum); 65% Sn, 35% Ni; and a Sn–Sb alloy.—H. R. M.

Columbia-Geneva Hikes Flat Rolled Capacity 68% with Tin Plate Extension. R. T. Reinhardt. (*Western Metals*, 1953, **11**, June, 45–47). A brief illustrated description is given of the recently expanded flat rolling and tinning facilities of the U.S. Steel Corporation's Columbia-Geneva Division, Cal.

Comparative Fields of Application of Electrolytic and Hot-Dip Tinplate. W. R. Lewis. (*Met. Ital.*, 1955, **47**, May, 210–215). [In Italian]. The author describes the great strides which have been made in the production of electrolytic tinplate in the last few years—particularly in the years of shortage during the war. The relative merits of electrolytic and hot-dip tinplate are discussed.—M. D. J. B.

Cystine as an Addition Agent in the Electrodeposition of Copper. A. J. Sukava and C. A. Winkler. (*Canad. J. Chem.*, 1955, **33**, May, 961–970). To assist in understanding the behaviour of gelatine as an addition agent, the effects of the simple thioamino acids cystine and methionine, and also of thiourea, were studied.—T. E. D.

The Use of Clad Metals. H. Schwartz. (*Product Eng.*, 1955, **26**, June, 162–166). The advantages of composite metals are discussed, and a list is given of the commercial application of a number of clad metals. The four major groups of combinations are classified, and the various types of cladding are described briefly.—E. A. C.

Brass Plating. K. G. Compton, R. A. Ehrhardt, and G. Bittrich. (*Plating*, 1954, **41**, Dec., 1431–1439). The effect of variation in pH, temperature, free cyanide content, metal content, and Cu/Zn ratio of a brass-plating bath on the uniformity, and composition of electrodeposited brass was investigated mainly with the object of producing coatings for bonding rubber.—A. D. H.

Metallizing for Corrosion Prevention. A. P. Shepard and R. J. McWaters. (*Corrosion*, 1955, **11**, Mar., 29–32). The application of zinc and aluminium coatings by the wire process is outlined, including reference to surface preparation, bend strength, and organic sealers.—J. F. S.

Fused-in-Place Spray Metallized Coatings. S. Tour. (*Welding J.*, 1955, **34**, Apr., 329–336). Methods of metallizing and fusing are discussed. Several fused-in-place spray-metallized coatings are investigated and photomicrographs are given which show the structure of coated alloys, and spray-coated steel.—U. E.

Aluminium Coating Process Developed for Iron and Steel Wire. B. S. Westerman. (*Iron Steel Eng.*, 1955, **32**, Mar., 126–130). This article describes a continuous hot-dip aluminium coating process for iron and steel wire developed by the Page Steel and Wire Division of American Chain and Cable Co. Inc.—M. D. J. B.

The Use of Silicone Resins in Protective Coatings. T. W. Watson. (*Trans. Inst. Metal Finishing*, 1954, **30**, 299–306).

POWDER METALLURGY

Infiltration with Copper Extends Range of Usefulness of Powdered Iron Gears and Cams. (*Precision Met. Mold.*, 1954, **12**, Dec., 41–42). The advantages of copper-infiltrated powder iron components are discussed with particular reference to various types of gear and cam.—D. H.

Powder Metallurgy. R. Cavé. (*Mém. Artillerie Fran.*, 1955, **29**, (1), 189–251; (2), 257–304). The various methods of producing metal powders are described, with some data on particle size. Compression is considered next, with notes on the behaviour of powders during compression, and on the presses used. The theory of sintering of pure powders and of mixtures, with and without a liquid phase, is examined, and sintering furnaces are briefly described. The physical and mechanical properties of sintered products are given. The production of items from sintered iron and steel is described, with details of the mechanical characteristics and heat-treatment of the products.—T. E. D.

A New Method of Determining Grain Size and Specific Surface of Powders Used in Metalloceramics. B. V. Deryagin, N. N. Zakhavaeva, and M. V. Talaev. (*Zhur. Tekhn. Fiz.*, 1955, **25**, (5), 881–886). [In Russian]. A description of the method and apparatus used is given. The method is based on the filtration of rarefied air through the powder investigated and measuring its resistance to flow.—V. G.

Applicability of Powder Metallurgy to Problems of High Temperature Materials. G. M. Ault and G. C. Deutsch. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**; *J. Met.*, 1954, **6**; Nov., Section 1, 1214–1230). The authors review some of the efforts made to utilize powder metallurgy to solve problems encountered when using alloys at high temperatures. Wrought and sintered alloys are first compared, and the properties of sintered aluminium powder, porous materials for transpiration cooling, and molybdenum alloys are discussed. Particular attention is given to metal–ceramic and similar mixtures, with examples of their application.—G. F.

Now: High Strength Alloy Steel Powder Metal Parts. (*Product Eng.*, 1955, **26**, Mar., 133–138). Pre-alloyed steel powders are now available for production use to make high-density, high-strength parts. Comparative details of gears corresponding to SAE 4600 steel made in this way and cut steel gears are given. Results were very satisfactory both for wear and strength and the surface finish is better than with cut gears.—A. M. F.

Fibre Metallurgy. A. G. Metcalfe, C. H. Sump, and W. C. Troy. (*Metal Progress*, 1955, **67**, Mar., 81–84). The results are discussed of using metal fibres or filaments as raw materials for compacting and sintering a finished part. Bodies with novel properties may be prepared having a large range of porosities combined with high strength and toughness.

Powdered Metal Gears for Tougher Jobs. (*Steel*, 1955, **136**, Feb. 14, 84–86). The development and acceptance of powdered-metal gears for hydraulic pumps is described. They are made from prealloyed powder and, while maintaining quality, have resulted in 20% cost reduction.—D. L. C. P.

Pressure's on the Press Builders. B. B. Belden. (*Steel*, 1954, **135**, Nov. 8, 90–91). The action of 50- and 100-ton presses built by Baldwin–Lima–Hamilton Corp., Pa., specifically for pressing metal-powder parts is described. Flanged parts of uniform density can be made.—D. L. C. P.

PROPERTIES AND TESTS

Corrosion Fatigue of Low-Carbon Steel Welded Joints. A. M. Abd-El-Wahed. (*Brit. Welding J.*, 1955, **2**, June, 247–253). An investigation is described on the corrosion fatigue of welded joints; 0·15% C steel was exposed to sodium chloride solution. The corrosion-fatigue tests are compared with measured hardness values and it was found that endurance under corrosion fatigue of the successive zones across the welded joints is roughly proportional to the hardness values.—U. E.

The Dispersion of Shore Hardness Values and Grain Size of Carbon Steels. T. Saga and O. Miyakawa. (*Mem. Fac. Techn.*, 1954, (4), 165–178). The distribution of Shore hardness values was shown to be normal. In heterogeneous materials (e.g. C steel) the dispersion is greater in coarse- than in fine-grained materials; in pure Fe and eutectoid steel, however, grain size does not influence the dispersion. With increase in hardness, the standard deviation of Shore values increases, but the coefficient of variation is hardly changed.—K. E. J.

Pressure-Cutting Method for the Evaluation of Cutting Power and Preserving of Cutting Power of Knives. H. Klemm. (*Stahl u. Eisen*, 1955, **75**, May 19, 644–646). Three steels, one containing 38·6% W, 3·54% Cr, and 0·18% Mo (B.H.N. 695) and the others plain carbon steels with 0·67% C (B.H.N. 580) and 0·11% C (B.H.N. 90) were tested for cutting power and its preserving. Cutting power was determined for a number of cutting angles on lead cylinders by applying a certain load to the test knife. The chord length cut into the lead cylinder is a measure for the cutting power. For the determination of preserving of cutting power, steel cylinders of Rockwell C hardness 68 were used. The difference in cutting power between the high-tungsten steel and the 0·67% C steel is slight.—T. G.

Experiments with Pyramidal Indenters. D. S. Dugdale. (*J. Mech. Phys. Solids*, 1955, **3**, Apr., 197–211). From experiments with indenters on cold-drawn low-carbon steel, cold-rolled copper and silicon aluminium, and measurements of the yield stresses of these materials in torsion, the dependence on semi-apical angle of the ratio of indentation pressure to yield stress in shear is obtained for square pyramids roughened and lubricated, triangular pyramids and cones. Using pyramidal indenters with vertex semi-angles 20–80° for making impressions in annealed copper and heat-treated 13·4% Mn, 0·8% C steel, a method is found for relating hardness to stress/strain curve. A distinction is made between 'sinking in' and 'raised lip' impressions.—J. G. W.

Fundamental Study on Making Standard Block for Hardness Measurement. III. The effect of subzero treatment on the hardness distribution. T. Mitsuhashi, M. Ueno, and S. Yokoi. (*J. Mech. Lab.*, 1955, **9**, Jan., 1–19). The effects of sub-zero treatment on the hardness distribution in blocks of 0·77–1·29% carbon steel are reported. Treatments included quenching and holding at − 30° and − 75° C, singly or repeatedly, with and without tempering. The effects are interpreted with the aid of statistical significance tests. The hardness distribution was improved by single, two-step sub-zero treatment, sub-zero treatment followed by tempering, in that order.—J. G. W.

Hardness of Metallic Materials. E. Kappler. (*Z.VdI*, 1955, **97**, May 15, 479–485). The Meyer hardness and its relation to the U.T.S. were investigated theoretically and experimentally, leading to the proposal of a new definition of hardness which is independent of load and ball diameter in the Brinell test, and suggesting that the hardness/tensile-strength rates approaches a constant value for a fully work-hardened material (3·7 for pure iron).—J. G. W.

Performance Tests on Rockwell Hardness Indenters. R. S. Marriner. (*Metalworking Prod.*, 1955, **99**, June 24, 1145–1149; *Engineering*, 1955, **180**, July 1, 17–19; *Machinery*, 1955, **87**, July 1, 32–38; *Engineer*, 1955, **200**, July 8, 56–58; *Sheet Metal Ind.*, 1955, **32**, Aug., 610–616). Truth of form of the indentor is a basic requirement for hardness measurement by indentation. Manufacture to B.S. specification is not easy. The N.P.L. have established, by measurement, the presence of a form error, which is not covered in the standard, and which is likely to influence performance.—M. A. K.

Non-Contact Hardness Tester Sorts Castings Magnetically. M. J. Diamond. (*Metalworking Prod.*, 1955, **99**, June 17, 1091–1092). Automatic magnetic comparator measures hardness of Arma-steel rocker arms at 3000 per hour. Using magnetic retentivity of steel which varies with hardness, non-destructive test provides 100% inspection, rejects parts above or below preselected hardness levels.—M. A. K.

The Significance of Microhardness Testing. A. P. Miodownik. (*Bull. Inst. Metals*, 1955, **2**, June, 258–262). Deviation and scatter in microhardness testing at low loads are examined and their causes explained.—B. G. B.

How to Improve the Quality of Deep Drawing Steel. E. R. Morgan and J. C. Shyne. (*Iron Age*, 1955, **175**, June 23, 91–94). The problem of strain ageing in steels for deep drawing is considered. Ways to avoid strain ageing are noted; stabilization by vanadium shows considerable promise.—D. L. C. P.

An Investigation of Strain Aging in Fatigue. J. C. Levy and G. M. Sinclair. (*Amer. Soc. Test. Mat.*, Preprint, 1955, No. 70). Fatigue tests have been carried out on a low-carbon steel at a rate of 2600 load cycles per minute, at temperatures up to 700° F and at a constant stress amplitude of 35,000 lb/in². A number of specimens (usually 10) were tested at each temperature and the results were analysed statistically. A peak in fatigue life at 450° F was found. Subsequent tests showed that the magnitude of the peak depended on the amount of carbon and nitrogen in solid solution. A theory to account for these results has been developed.—B. G. B.

The Effect of Temper-Rolling on the Strain-Ageing of Low-Carbon Steels. H. P. Tardif and C. S. Ball. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 9–19). [This issue].

Mechanism of a New Type of Ageing Phenomenon in Iron and Steel on Anodic Surcharging. K. C. Som and G. P. Chatterjee. (*Trans. Indian Inst. Met.*, 1955, **7**, 197–210). The hardness of hot-forged and annealed steel decreases on anodically surcharging but then increases on ageing at room temperature. Attempts have been made in this paper to correlate experimental data of the hardness values as functions of surcharging and ageing time.—D. H.

Influence of Annealing at 650° C on Impact Properties of Work-Hardened Mild Steels. G. Sehlberg. (*Jernkontorets Ann.*, 1955, **139**, (4), 215–224). [In Swedish]. Two low-carbon steels were repeatedly cold worked by stretching and then annealed on each occasion. The treatment did not influence the ageing

tendencies of the steel, although it did not always regain its original notch-toughness, especially if annealing was carried out without recrystallization occurring. The notch-toughness appeared to decrease in direct proportion to the number of stretching and annealing operations. In one sample the notch-toughness greatly exceeded the initial value. Recrystallization had clearly occurred, apparently displacing the temperature/notch-toughness curve towards lower temperatures and resulting in increased strength at + 20° C.

Fatigue Life of Steel. I—Beams at Normal and Sub-zero Temperatures. J. Dubuc, T. A. Monti, and G. Welter. (*Eng. J.*, 1955, **38**, May, 607–614, 626). A programme of tests was carried out on 10-in. 21-lb/ft rolled beams, and equivalent riveted and welded beams made from rimmed and killed steels. The transition temperature, determined by Charpy testing, was $< -40°$ F. Fatigue resistance was better at $-40°$ than at $+70°$ F. The welded beams had the best resistance at 70°, the rolled beams at − 40°, and the riveted beams the worst at both temperatures. Welded beams behaved physically in the same way as the rolled beams, since all types exhibited the same fracture characteristics.

How Stainless Steels Rate for High Temperature Aircraft Service. E. A. Loria. (*Iron Age*, 1955, **175**, Apr. 7, 119–122; Apr. 14, 103–106). The high-temperature properties of some specific stainless steels are described, with particular reference to withstanding kinetic heating of aircraft surfaces.—D. L. C. P.

Creep Tests on 1% Chromium, 0·3% Molybdenum Steels. S. Terai. (*Sumitomo Metals*, 1955, **7**, Jan., 17–26). [In Japanese]. Tests with forged bars were made at 500°, 550°, and 600° C for 600–1200 h. Results are compared with those of high-temperature tension and short-time creep tests. At 500° C the steel had the same strength as other Cr–Mo steels with higher Mo contents, but the strength fell rapidly at higher temperature. Creep curves are analysed mathematically; transient creep is less temperature-sensitive than minimum-rate creep.—K. E. J.

Strain Measurement for High-Temperature Long-Time Creep Testing. I. M. Sumitomo, T. Hasegawa, O. Ochiai, and H. Kuwa. (*Sumitomo Metals*, 1955, **7**, Jan., 27–34). [In Japanese]. Difficulties in the use of a creep type extensometer (as reported by G. V. Smith) for strain measurement are discussed. Satisfactory results were obtained with the use of a special extenso-arm, fixed with the flange at the reducing section of the specimen.—K. E. J.

Heat Resistant Cast High Alloys. C. K. Lockwood. (*Product Eng.*, 1955, **26**, Feb., 163–167). The use of cast Fe–Cr–Ni components for service temperatures up to 2150° F is discussed and the recommended applications for 13 A.C.I. designated alloys are described. The important properties to be considered at high temperatures are hot strength, thermal expansions, structural stability, corrosion resistance, resistance to thermal fatigue, and hot ductility.—A. M. F.

Some Fundamental Experiments on High-Temperature Creep. J. E. Dorn. (*J. Mech. Phys. Solids*, 1955, **3**, Jan., 85–116). A critical analysis of previously published and as yet unpublished experiments on high-temperature creep is presented, as a foundation on which a realistic theory may be constructed. It is suggested that transients attending loading and unloading, and the coincidence of the activation energy for creep ΔH with that for self-diffusion, indicate that high-temperature creep might be ascribed to a dislocation climb process.—J. G. W.

Where Heat is King. A. Levy. (*Steel*, 1955, **136**, Jan. 31, 86–89; Feb. 7, 146–152). A review is presented of materials available for high-temperature use in modern power plants, and the conditions they are required to withstand are illustrated by examples. The properties of high-temperature alloys and methods of fabrication are considered.—D. L. C. P.

Study of Materials for Valve Seatings at High Temperature and High Pressure. (IV). M. Okano and H. Hotta. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **15**, July, 305–306). [In Japanese]. Tests on Co–Cr–W, 13% Cr, and 18/8 steel, and 18% Ni–Si–Mn–Cr iron included abrasion tests at room and high temperatures, microscopical examination, and corrosion resistance to NaCl, HCl, H_2SO_4, and HNO_3.—K. E. J.

Nitrogen as the Alloying Element in Steel. VII. Y. Imai and T. Ishizaki. (*Nippon Kinzoku Gakkai-Si*, 1951, **B**, **6**, June, 258–262; 262–268). [In Japanese]. Tests on steel annealed in different atmospheres and subjected to cold work showed that blue-brittleness is due to the precipitation of nitride or carbide from α-iron as the result of stress; brittleness from nitride is more pronounced in the lower temp. range. Further tests on steel air-cooled from 950° C showed that blue-brittleness decreases with increase of Si content, and that it increases slightly with O_2 additions.—K. E. J.

The Relation between Humidity in the Air and Hydrogen Content in Steel. F. Kodama and Y. Miyamoto. (*Sumitomo Metals*, 1954, **6**, Jan., 9–12). [In Japanese]. Works and other studies suggest that H_2 content of steel is affected by atmospheric humidity; the effect is examined statistically.—K. E. J.

A Study of the Correlations Between Different Mechanical Tests on Common Grey Cast Irons. F. Danis and E. Doat. (*Fonderie*, 1955, Apr., 4451–4464). Results are presented of a large number of mechanical tests on 20- and 30-mm test bars of grey cast iron from 16 different foundries. Good linear correlations were established between tensile strength and strength in bending, tensile strength and shear strength, and strength in bending and shear strength. The results were analysed to show that both phosphorus content and free cementite influence the various mechanical properties and the correlations between them.—B. C. W.

Trace Impurities: Effect on the Properties of Iron. N. P. Allen. (*Iron Steel*, 1955, **28**, Mar., 85–88; *J. Birm. Met. Soc.*, 1955, **35**, July, 3–9). Experiments on the toughness of iron and its alloys have indicated that this property is principally influenced by quite small quantities of certain impurities becoming incorporated in the iron crystal, and that the effects of major alloying elements are often their effects on the behaviour of these trace impurities. The author describes the steps by which this opinion has been reached, quoting experimental results, and discusses the brittleness of iron and its alloys.—G. F.

Improvement in the Composition of Alloy Steel for Metal-Cutting Tools. Yu. A. Geller. (*Stanki i Instrument*, 1955, (2), 22–25). [In Russian]. The qualities required of alloy tool steels in general are considered, together with ways in which those of frequently used types may be improved. The effects of alloying elements on machinability, sensitivity to overheating, decarburization on heating, hardenability, mechanical properties, and deformation during hardening are discussed. Various attempts at obtaining improved low-alloy and complex-alloy steels and the results achieved are considered.—S. K.

The Development of Rules for the Use of Steels. J. Dutheil. (*Mem. Soc. Ing. Civils France*, 1954, **107**, July-Sept., 255–265). A short account of methods used for calculating the strength of steel parts is presented.—B. G. B.

The Development of Stainless Steels and Their Use. J. Dedieu. (*Mem. Soc. Ing. Civils France*, 1955, **107**, Jan.-Feb., 10–18). A comprehensive review of this subject is presented. The effect of the various alloying elements on the properties of stainless steels is discussed and the chemical and mechanical properties of these steels are described.—B. G. B.

More Muscles in Steel. A. G. Gray. (*Steel*, 1955, **136**, Apr. 25, 96–99). Compositions, properties, applications, and treatments of ultra-high-strength steels are considered. Materials may have tensile properties in the practical range of 220,000–325,000 lb/in².—D. L. C. P.

Radioactive Isotopes. (*Aircraft Prod.*, 1955, **17**, May, 170–175).

Study of the Radiation Stability of Austenitic Type 347 Stainless Steel. M. B. Reynolds, J. R. Low, jun., and L. O. Sullivan. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Apr., 555–559). The effect of neutron bombardment on the stability of austenitic stainless steel has been studied by a magnetic technique. The relation of the ferrite content to magnetic properties is given, an apparatus suitable for measuring the ferromagnetic saturation induction being described. Exposure to a neutron flux causes a slight increase in the ferrite content, the change increasing with increasing exposure time and with increasing initial ferrite content. The similarity of the irradiation effect to the effect of annealing is pointed out, and the possible effect on the density of austenitic stainless steel is discussed.—G. F.

Extra Low Carbon Stainless Steels. (*Aciers Fins Spéc. Franç.*, 1954, Dec., 87–89). A brief account is given of the development of the extra-low-carbon austenitic steels which, in France, are gradually replacing the medium- and low-carbon steels.—E. A. C.

The Properties of a High-Manganese Austenitic Stainless Steel. G. N. Flint and L. H. Toft. (*Metallurgia*, 1955, **51**, Mar., 125–129). Although in some media the corrosion-resisting properties of a stainless steel containing 18% Cr,

10% Mn, 2% Ni and stabilized with titanium are equal to those of a Ti-stabilized 18/8 Cr–Ni steel, there are many industrial applications for which the high-manganese steel would not be suitable. The ductility and deep drawing properties of the high-manganese steel are inferior to those of the 18/8 type.—B. G. B.

New Stainless Alloy " Bridges Gap " Between 300 and 400 Series. A. J. Lena. (*Iron Age*, 1954, **174**, Dec. 2, 113–116). The material " Allegheny Metal 350 " (" AM 350 ") is introduced. Nominal composition is C 0·08%, Mn 0·6%, Si 0·4%, Cr 17·0%, Ni 4·2%, Mo 2·75%. The annealed alloy is essentially austenitic with good ductility, but can be hardened by heat-treatment. Hardening by sub-zero cooling is preferred.—D. L. C. P.

METALLOGRAPHY

Some Observations on Grain-Growth Characteristics of Austenite. T. Kawai and Y. Masuko. (*Tetsu to Hagane*, 1955, **41**, Apr., 435–442). [In Japanese]. Grain size and grain-growth characteristics were observed during melting and teeming, between the ladle sample and the finished heat, and in relation to duplex-graining, in Cr–Mo, Al-killed, and Ni–Cr–Mo steels. Austenitic grain size has a close relationship with the amount of acid-soluble Al in the steel.—K. E. J.

Examination of Crystal Boundaries in Deformed Metals by means of Microhardness Measurement. H. E. Tuchschmid. (*Schweiz. Arch. Wiss. Techn.*, 1954, **20**, Dec., 382–383). The author describes tests carried out on 18/8 stainless steel and an Al alloy in order to detect the influence of crystal boundary precipitation on work hardening by means of microhardness measurements. The method was not found to be sufficiently sensitive to detect work hardening differences between crystal centres and crystal boundaries brought about by plastic deformation. However, it was confirmed that changes in the homogeneity of a microstructure due to plastic deformation could be shown up by variations in the Vickers hardness along a line crossing the structure as previously shown by Boas and Hargreaves.—J. R. P.

Sub-structures in Ferrite. P. Samuel and A. G. Quarrell. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 20–30). [This issue].

Crystallization of the Ledeburite Eutectic. E. Scheil and D. Pohl. (*Arch. Eisenhüttenwesen*, 1955, **26**, Feb., 105–108). Cooling curves of grey and white iron were taken to decide whether the graphite precipitates directly from the melt or forms by decomposition of cementite. Both eutectics could be supercooled strongly after superheating. With the onset of crystallization, the temperature increased rapidly to almost the equilibrium temperature in the case of ledeburite formation, whereas the temperature rise in the case of the crystallization of the graphite eutectic was only slight in spite of high supercooling. The authors conclude, therefore, that the graphite eutectic forms directly from the melt.—T. G.

Some Observations on Isothermal Austenite Transformation Near the M_S Temperature. O. Schaaber. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Apr., 559–560). The author has carried out dilatometric and inductive measurement of isothermal austenite transformation in a number of low-alloy steels, at various temperatures near the M_S temperature. The results are presented and interpreted.

The Influence of Induction Heating on Structural Transformations of High-Chromium Tool Steel. E. P. Mogilevskii. (*Zhur. Tekhn. Fiz.*, 1954, **24**, (12), 2202–2208). [In Russian]. *X*12 steel of the following composition was investigated: C 2·12%, Si 0·21%, Mn 0·29%, and Cr 12·2%. Induction heating under correct conditions can secure all transformation of the carbide phase and produce hardening to a required degree, the velocity of the carbides solution during induction heating is considerably increased, and a higher velocity of induction heating methods shifts all processes taking place in steel into a higher temperature region including the temperature of the formation of the eutectic.—V. G.

Temperature Conditions of Phase Transformations During Induction Heating of Steel. I. N. Kidin and M. G. Kogan. (*Zhur. Tekhn. Fiz.*, 1954, **24**, (11), 2011–2024). [In Russian]. Basic features of kinetics of induction heating of steel were investigated. The heat effect of pearlite–austenite transformation has no practical influence on the kinetics of induction heating. The appearance of a flat part and an inflection on thermal curves is due to a decrease of power consumed by the metal caused by the loss of ferromagnetic properties in surface layers.—V. G.

Transformations in Iron–Carbon Alloys During Heating with an Electric Current. V. N. Gridnev. (*Zhur. Tekhn. Fiz.*, 1954, **24**, (10), 1812–1822). [In Russian]. The mechanism and kinetics of transformation of a number of non-ferrous and iron alloys were investigated. Non-diffusion transformations are the main form of transformations, whilst diffusion transformations are only secondary superimposed processes.—V. G.

The Problem of the Initial Temperature of a Pearlite–Austenite Transformation on Rapid Heating. D. M. Gurevich. (*Zhur. Tekhn. Fiz.*, 1954, **24**, (7), 1268–1272). [In Russian]. The influence of heating rate on the temperature of the beginning of pearlite–austenite transformation was investigated. Variations in the heating rate from 10° to 700° C/s had no practical influence on the initial temperature of transformation.—V. G.

Transition Temperature Behaviour of Pressure Vessel Steels. L. J. McGeady. (*Welding J.*, 1955, **34**, Jan., 1s–11s). The effects of temperature on pressure vessel steels in the range + 32° to − 50° F, with particular emphasis on transition temperature behaviour, was investigated. The transition temperatures of the steels under investigation depend on carbon content, ferritic grain size, and phosphorus, silicon, and manganese content. Lowest transition temperatures are most uniformly obtainable in steel deoxidized with both Al and Si.—U. E.

Electron-Optical Observations of Transformation in Eutectoid Steel. G. W. Rathenau and G. Baas. (*Acta Met.*, 1954, **2**, Nov., 875–883). Using the electron-emission microscope in which an image of a heated polished surface coated with cesium or barium is formed by electron emission, the $\gamma \rightleftharpoons$ pearlite inversion has been studied in a eutectoid steel of high purity. The pearlitic colonies generally cross austenite grain boundaries, strain-induced grain boundary migration occurs within austenite, and by austenitizing partially transformed austenite twinning has been stimulated within the austenite.—A. D. H.

The Superlattice In Sendust. R. Garrod and L. M. Hogan. (*Acta Met.*, 1954, **2**, Nov., 887–888). A letter reporting an investigation of the transition temperature for the order–disorder transformation in Sendust (Si 8–11%, Si 4·5–8%, Fe balance) concludes that the transition temperature lies at or near the melting point or that the transformation cannot be surprised by quenching. The degree of order is probably reduced by cold work or by rapid cooling from high temperatures.—A. D. H.

The Iron–Carbon–Silicon Ternary Equilibrium Diagram. (*J. inf. tech. Indust. Fond.*, 1955, Jan., 21–25). The influence of Si on the Fe–C phase diagram is explained and the effect of Si on the carbon saturation of iron are discussed.—B. G. B.

The Equilibrium Diagram for Iron–Carbon Alloys. (*J. inf. tech. Indust. Fond.*, 1954, Oct., 19–22).

Fundamentals of the Fe–C Diagram. (*Schweissen u. Schneiden*, 1955, **7**, Feb., 61–66). The Fe-C diagram is discussed in detail from the pure iron crystal structure to that containing carbon. The effect of alloying elements on the constitution of Fe–C alloys is briefly considered and special attention is given to that part of the diagram representing Fe–C alloys which can be welded.—U. E.

CORROSION

Demineralization of Boiler Feed Water. G. Costes. (*Chaleur et Ind.*, 1955, **36**, Apr., 103–125). After discussing ion exchange in general, the types of resin used, and the mechanism of the exchange, the determination of the amount of resin needed for a particular project is described. Amberlite IRA 400 and 410 and Nalcite SBR and SAR are examined in some detail. Five different demineralizing schemes are given as flow-sheets. The physical properties of the resins are indicated, and control methods are summarized.—T. E. D.

Cathodic Protection of Open Box Coolers. J. P. H. Zutphen. (*Corrosion*, 1955, **11**, Jan., 53–56). Cathodic protection has been successfully applied to the outside of steel pipes in brackish cooling water. Graphite anodes were used to reduce maintenance.—J. F. S.

Notes on a System for Rating Pitting Corrosion. R. W. Henke. (*Corrosion*, 1955, **11**, Jan., 50–52). A code system for describing corrosion pits is proposed covering their dimensions and shape, the area pitted, and the duration of exposure.—J. F. S.

Effect of Design, Fabrication and Installation on the Performance of Stainless Steel Equipment. J. A. Collins. (*Corro-*

sion, 1955, **11**, Jan., 27–34). For maximum corrosion resistance of stainless-steel equipment, the nature of surface films and conditions for their occurrence, and maintenance must be understood. Nine rules to limit corrosion are: use butt-type joints; do not join dissimilar metals without insulation; make drainage free and washing easy; avoid sharp corners and recesses; support equipment on legs; avoid turbulent flow and high velocities; avoid contact with porous materials; anneal or stress-relieve; clean frequently.—J. F. S.

Effect of Minor Constituents on the Intergranular Corrosion of Austenitic Stainless Steel. J. J. Heger and J. L. Hamilton. (*Corrosion*, 1955, **11**, Jan., 22–26). Results of standard laboratory tests of the corrosion resistance of 18/8 stainless steel indicate the precipitation of other minor constituents besides chromium carbide. A reassessment of data of Bain, Rutherford, and Aborn, together with present results, indicate that carbon content must be below 0·009% before freedom from intergranular corrosion can be expected. Suggestions are put forward to explain the intergranular corrosion of 18/8 Mo steels. The need for an instrument capable of making microchemical analyses is mentioned.—J. F. S.

Laboratory Evaluation of Inhibitors for Sweet Gas-Condensate Wells. P. J. Raifsnider, R. S. Treseder, and A. Wachter. (*Corrosion*, 1955, **11**, Jan., 19–21). Simple test methods are described for the laboratory evaluation of corrosion inhibitors for use in sweet gas-condensate wells.—J. F. S.

Catastrophic Corrosion Resulting from Vanadium Pentoxide in Fuel Oil Ash. A. DeS. Brasunas. (*Corrosion*, 1955, **11**, Jan., 17–18). Corrosion of heat-resistant alloys exposed to the combustion products of fuel oil at high temperatures can accelerate with time to over 100 in./year. Vanadium oxide in the ash is the cause. The cure is unknown, though Ni-rich alloys are better than average. Additions to the oil have also been tried. Vanadium contents of oil from four sources are listed.—J. F. S.

Use of Organic Inhibitors in Refinery Distillation Process Equipment. G. E. Purdy. (*Corrosion*, 1955, **11**, Jan., 64–67).

Corrosion in the Brewing Industry. (*Corrosion Techn.*, 1955, **2**, Apr., 117–119). The best methods of protecting the various parts of breweries, including the tun room, the cellars, liquor tanks and bottling stores, are discussed.—L. E. W.

Modern Swedish Corrosion Research. (*Corrosion Techn.*, 1955, **2**, Apr., 123–124).

Corrosion of Iron by Oxygen-Contaminated Sodium. G. W. Horsley. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 43–48). [This issue].

ANALYSIS

Polarographic Determination of Magnesium in Coal Ash and Coke Ash. L. J. Edgcombe and G. R. E. C. Gregory. (*Analyst*, 1955, **80**, Mar., 236–237).

Direct Volumetric Determination of Magnesium in Calcareous Minerals. R. F. Muraca and M. T. Reitz. (*Chem. Analyst*, 1954, **43**, Sept., 73–74). Calcium is separated from magnesium by precipitating the latter with sodium hydroxide in presence of mannitol. The magnesium hydroxide is dissolved and titrated with EDTA. Calcium may be determined in the mannitol filtrate.—R. P.

Determination of Free Lime in Slag. H. Gotô and Y. Kakita. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1955, A, **7**, Apr., 135–139). Free lime in several slags was determined by the McPherson–Forbrich method. Results of the analyses, completed within 30 min, are quoted.—J. G. W.

A Contribution to the Study of Anodic Oxidation of Cast Irons and the Measurement of Its Rate by Photo-electric Reflectometry. A. Roos. (*Rev. Mét.*, 1955, **52**, June, 467–472). The rate of anodic oxidation is defined as the rate at which the oxide film increases over a given area of about 1 cm². A photo-electric cell device is described for measuring the film. Two oxidation phases are distinguished; while the second is related to the percentage of silicate inclusions in the iron, which can be rapidly determined, the first was studied in relation to the effect of foreign ions on the rate of oxidation.

The Problem of Reference Standards in Spectrography. M. E.-V. Rouir. (*17th Cong. G.A.M.S.*, 1954, June 23–25, 131–139). After discussing various methods for the preparation of spectrographic standards, the author states that the solution technique is to be preferred to others.—R. P.

The Influence of the Structural Constituents of Steels on the Values of ΔS. J. M. Lopez de Azcona and E. Asensi Alvarez Arenas. (*17th Cong. G.A.M.S.*, 1954, June 23–25, 101–115). The authors used a Hilger large-quartz spectrograph and the line-pair Fe II 2298·23Å/C III 2296·8 Å. Their tests show that the values of ΔS vary with the microstructure of steels, being smaller for martensite than for pearlite. Results obtained are explained theoretically.—R. P.

Methods of Sampling and Analysing Liquid Steel for Hydrogen. F. De Kazinczy. (*Jernkontorets Ann.*, 1955, **139**, (5), 309–325). [In Swedish]. After critically reviewing methods so far evolved, the author describes a new vacuum-fusion technique in which the sample is melted in a graphite crucible in a water-cooled quartz tube and the evolved gases rapidly pumped off. The water jacket is removed and the metallic film on the quartz tube is heated to 600–700° C for 15 s, thus driving off any adsorbed hydrogen. The latter is determined by diffusion through a Pd membrane, accuracy limits being $\pm$ 0·004 cm³ of H_2.—G. G. K.

The Indirect Complexometric Determination of Molybdenum. A. De Sousa. (*Anal. Chim. Acta*, 1955, **12**, Mar., 215–217). [In French]. A rapid method is described for the indirect determination of molybdenum in its ores and alloys. A molybdate solution is treated with calcium chloride, the precipitated calcium molybdate dissolved in HCl, evaporated and baked, and the resulting mixture of molybdenic acid and calcium chloride treated with hot water to dissolve the calcium chloride, which is filtered off. The filtrate is adjusted to a pH > 12 with sodium hydroxide, and titrated with standard EDTA using Murexide as indicator.—L. D. H.

The Use of the Thermobalance in Analytical Chemistry. F. Claisse, F. East, and F. Abesque. (*Canad. Dep. Mines, Laboratories Branch*, PR. No. 305, 1954). The principle of the Chevenard-type thermobalance is described, and detailed examples of its application to the analysis of mineral constituents are worked out.—L. D. H.

Determination of Barium in Iron Ores in the Presence of Calcium and Sulphates. O. Engel and J. Kadlec. (*Hutnické Listy*, 1955, **10**, (5), 294–296). [In Czech].—P. F.

Polarographic Reduction of the Iron-Triethanolamine Complex in the Presence of Manganese. J. Říha and L. Šerák. (*Chem. Listy*, 1955, **49**, (1), 32–36). [In Czech].—P. F.

An Instrument for the Rapid Quantitative Oscillographic Analysis by Means of Polarography. P. Valenta and J. Vogel. (*Chem. Listy*, 1955, **49**, (3), 361–366). [In Czech].—P. F.

Complexometric Titrations. (Chelatometry). 1,2-Diaminocyclohexane-N,N,N′,N′-tetra-acetic Acid as a Volumetric Reagent: Determination of Iron, Aluminium and Titanium. Z. Šír and R. Přibil. (*Chem. Listy*, 1955, **49**, (5), 679–683). [In Czech].—P. F.

Complexometric Titrations. (Chelatometry). 1,2-Diaminocyclohexane-N,N,N′,N′-tetra-acetic Acid as a Volumetric Reagent: Successive Determinations of Iron and Manganese (Magnesium, Calcium), and Determination of Copper in the Presence of Iron, Nickel, Cobalt and Manganese. R. Přibil. (*Chem. Listy*, 1955, **49**, (2), 179–185). [In Czech].—P. F.

Contribution to the Polarographic Determination of Manganese and Iron. J. Pleva. (*Chem. Listy*, 1955, **49**, (2), 262–263). [In Czech].—P. F.

Simultaneous Determination of Aluminium and Phosphorus in Ferro-Alloys. O. Bělohlávek and J. Vobora. (*Hutnické Listy*, 1955, **10**, (5), 293–294). [In Czech].—P. F.

Determination of Tin in Ferro-Tungsten. O. Bělohlávek and J. Vobora. (*Hutnické Listy*, 1955, **10**, (4), 229–230). [In Czech].—P. F.

Review of Industrial Applications of Analysis, Control and Instrumentation. Ferrous Metallurgy. H. F. Beeghly. (*Analy. Chem.*, 1955, **27**, Apr., 611–614). Brief notes and 91 references cover the use of radioactive tracers, and the analysis of Al, B, C, Ce, Nb, Cu, gases and non-metallics, P, slags and refractories, S, Ti, and Zr in ferrous metals.—T. E. D.

Analytical Control by a Direct Reading Spectrometer. D. Manterfield. (*Rail. Steel Topics*, 1955, **3**, (1), 31–36). The applications of a photographic and a direct-reading spectrometer (Quantometer) to analytical control of steelmaking operations at Steel, Peech and Tozer.—A. D. H.

Rapid Nephelometry of Oxygen in Steel by Electrophotometer. S. Yama, Y. Niimi, and S. Inenaga. (*Sumitomo Metals*, 1955, **7**, Jan., 53–57). [In Japanese]. For low-C steel containing $\geqslant$ 0·20% C, a rapid method for determination of O_2 during smelting is based on nephelometry of Al_2O_3 by the spectrophotometer, conditions being suitably adjusted. The method requires 8 min only, shows an accuracy of $\pm$ 0·0025% of O_2, and gives satisfactory reproducibility.

Rapid Determination of Manganese in High Cobalt and Chromium Steel. E. Dotani. (*Sumitomo Metals*, 1955, **7**, Jan., 58–64). [In Japanese]. Mn cannot be determined directly by the rapid arsenite method if the steel contains $> 4\%$ of Co and $> 2\%$ of Cr. A method is given whereby Mn may be separated from large amounts of Fe, Co, and Cr by the use of KCN and NaOH solutions, and then determined by arsenite titration.—K. E. J.

An Improved Apparatus for the Determination of Gaseous Elements in Metals by Vacuum Fusion on a Micro Scale. J. N. Gregory and D. Mapper. (*Analyst*, 1955, **80**, Mar., 225–230). Improvements to the previously described apparatus relate mainly to more efficient pumping and recovery of the evolved gases, and the introduction of a low-pressure method of gas analysis. The latter enables results to be obtained in half a day, instead of 2 or 3 days.—T. E. D.

Spectrophotometric Determination of Niobium in Niobium-bearing Steels. J. L. Kassner, A. Garcia-Porrata, and E. L. Grove. (*Analy. Chem.*, 1955, **27**, Apr., 492–494). Only two separations are involved: a perchloric acid hydrolytic precipitation and a chloroform extraction of the metal derivative of 8-quinolinol. Finally, the method makes use of the yellow colour of chloroform solutions of niobium oxinate, which shows maximum absorption at 385 mμ.—T. E. D.

Method for Sparking Thin Sheet Samples for Spectrographic Analysis. F. P. Landis and L. P. Pepkowitz. (*Analy. Chem.*, 1955, **27**, Jan., 141–142). The method is applied to Mn and Nb determination in stainless steel. Heat produced by the spark produces high local temperatures leading to excessive volatilization of Mn and Nb with respect to the amount of iron volatilized. A flow of cooled He, which has a high thermal conductivity, is used on the upper or unsparked side of the sample.—T. E. D.

Determination of Chromium and Vanadium in Steels by a Rapid Method. B. E. Jaboulay. (*Chim. Analy.*, 1955, **37**, Mar., 97–99). After obtaining the Cr and V as chromic and vanadic acids either by the acid permanganate method or the perchloric-phosphoric method, Cr is determined with $FeSO_4$ and $KMnO_4$. Vanadium is then titrated with $FeSO_4$ in the presence of diphenylamine sulphonate of barium, which requires the presence of less phosphoric acid than when using ordinary diphenylamine as indicator.—T. E. D.

Progress in the Analysis of Ferrous Metals. E. Jaudon. (*Chim. Analy.*, 1955, **37**, Feb., 45–52; Mar., 104–111). Spectrography, spectrophotometry, and new methods used in separations (precipitation as an organic complex, electrolysis on to a mercury cathode, and masking of interfering elements) are discussed. Potentiometry, polarography, and chromatography are mentioned. Methods for the following elements are given: Al, As, B, C, Cr, Nb, and Ta, Ca, Cu, Fe, Mn, Mo, P, Si, S, Ti, V, and Zr. Methods for dissolved gases and inclusions are also considered.—T. E. D.

Application of Ion Exchange Resin to Chemical Analysis of Metals. I. Determination of Boron and Magnesium in Iron and Steel. T. Shiokawa and A. Sato. (*Nippon Kinzoku Gakkai-Si*, 1951, **B, 6**, June, 284–287). [In Japanese]. Details are given of analytical procedures for B and Mg, using the cation exchange resin 'Diaion K.'—K. E. J.

A Rapid Determination of Microquantities of Silicon in Steels. H. Gotô and Y. Kakita. (*Nippon Kinzoku Gakkai-Si*, 1951, **B, 15**, Sept., 448–450; 450–452). [In Japanese]. Colorimetric methods, using molybdenum blue, etc., were studied, using a Pulfrich photometer; 0·01% Si can be determined within 10 min, and standard solutions can be made up for use in a normal colorimeter.—K. E. J.

Improvement of the Method for Hydrogen Analysis in Daily Works Practice. T. Fujii. (*Sumitomo Metals*, 1954, **6**, Jan., 76–83). [In Japanese]. The laboratory vacuum-heating method was modified for rapid daily works analyses; duplicate furnaces, tubes, and pumps enabled two samples to be analysed simultaneously. Molten steel samples should be taken from the same point in the furnace, and should be water-cooled within 10 s of casting.—K. E. J.

Determination of Small Amount of Boron in Steel. S. Kiriyama and T. Kishi. (*Sumitomo Metals*, 1954, **6**, July, 171–183). [In Japanese]. Small amounts of B are separated from iron by a magnetic mercury cathode cell; Ti or V may be removed by oxine precipitation, H_2O_2 being added to prevent B adsorption. B is determined colorimetrically with an accuracy of 0·008–0·002%.—K. E. J.

Recent Developments in Direct Spectroscopic Analysis. C. Macq. (*Rev. Univ. Min.*, 1955, 9th series **11**, Feb., 76–81). An electronic high-tension generator for producing sparks, pulsating arcs, or continuous arcs is described. The instrument is capable of excellent reproducibility. A new concave diffraction grating using the Paschen–Runge mounting and a radius of curvature of 2m has been constructed by Bausch and Lomb. The framework on which the grating is mounted is kept at constant temperature. Electronic equipment for measuring the intensities of spectral lines using photomultiplier tubes and having circuits of high stability is described.

Practical Results of Production Control Using the Radio-Synthèse Direct Reading Spectrometer. Utilisation of Zero Order Reflected Beam as Reference. A. Hanrick, A. Hans, and M. Lacomble. (*Rev. Univ. Min.*, 1955, 9th series **11**, Feb., 81–85). The results obtained on a direct spectrometer manufactured by Radio-Synthèse, Brussels, are described. The analyses of Al and Si in steels are considered in detail. The error in analysis is considerably less using the zero-order reflected beam as a reference than when using an iron line as reference or the absolute technique.—B. G. B.

Comparison of Analytical and Spectroscopic Methods of Determining Total Aluminium in Steels. M. Lacomble and L. Dor. (*Rev. Univ. Min.*, 1955, 9th series **11**, Feb., 86–97). The gravimetric method for aluminium analysis using the precipitation of aluminium phosphate, the colorimetric estimation using Ferron reagent, and three spectroscopic techniques have been compared; 46 samples have been examined by each method. The results are presented in tabular form. The direct spectroscopic technique using the zero-order reflected ray as reference is the most exact and most rapid method.—B. G. B.

Colorimetric Determination of Phosphorus in Coal. L. Rodriguez Pire and C. Garcia Gutierrez. (*Inst. Nac. Carbon Bol. Inf.*, 1955, **4**, Mar., 84–101). [In Spanish]. Methods for the determination of phosphorus in solid fuels have been compared. Very good results may be obtained in a much shorter time by colorimetric methods. The advantages of Ellington and Adams' method are discussed.—P. S.

The Use of a Flame Photometer in Metallurgical Analysis. M. Hoffman and S. Sternal. (*Przeglad Odlewnictwa*, 1955, **5**, (5), 134–137). [In Polish].

Gas Analysis by Thermal-Conductivity Measurement. G. B. Brown and R. W. Dean. (*Instrument Eng.*, 1955, **1**, Apr., 145–150). The theory, scope, and limitations of the analysis of gases by thermal-conductivity measurements are described, and applications are discussed to the determination of CO_2 in flue gas and of SO_2 in the manufacture of sulphuric acid.

Quantitative Use of X-Ray Diffraction for Analysis of Iron Oxides in Gogebic Taconite of Wisconsin. R. S. Shoemaker and D. L. Harris. (*Min. Eng.*, 1955, **7**, May, 476–480). Goethite and hematite contents were determined in five taconite samples by a quantitative method based on the calibration of a recording X-ray spectrometer with standard samples. The goethite diffraction intensities were directly proportional to its content in mixtures with hematite and quartz. The hematite intensities were influenced by the other two minerals, and consequently standard reference curves were made up, using mixtures of known proportions of the three minerals.—K. E. J.

INDUSTRIAL USES AND APPLICATIONS

Revisions in A.I.S.I. Stainless Designations Reflect Industry Practice. (*Iron Age*, 1955, **175**, May 19, 122–123). Changes in the A.I.S.I. designations and analyses of stainless and heat-resisting steels are reported; they result from improved practice and elimination of government controls.—D. L. C. P.

Machines for the Manufacture of Wire Netting and Wire Grids. A. Jasper. (*Z.VdI*, 1955, **97**, May 15, 489–492).

The Steels of Reinforced Concrete Frames. M. Roš. (*Rev. Mét.*, 1955, **52**, Feb., 105–115). Steels used in reinforced concrete frames should have a high yield point, a high resistance to alternating stresses, and good adherence to the concrete. The author gives a classification, together with their properties, of the steels used for this purpose.—G. E. D.

Influence of Nail Design and Manufacturing Practices on Joint Strength. A. B. Dove. (*Wire and Wire Products*, 1955, **30**, June, 657–666, 724–725).

The Housing Problem and the Iron and Steel Industry. (*Aciers Fins Spéc. Franç.*, 1955, Mar., 7–10).

The Use of High Tensile Steel in Railway Coaching Stock. E. Bryan and J. W. Woodcok. (*Rail. Steel Topics*, 1955, **3**, (1), 21–30). The properties of Cor-Ten, Fortiweld, Cr–Mo, and 18/8 stainless steels are discussed and their application in open and closed section to structural members of railway passenger coaches is described.—A. D. H.

The Sheffield Cutlery Trade. C. N. Kington. (*Times Rev. Indust.*, 1955, **9**, June, 15–17).

Metallurgy and Metals of the Future. E. A. Fox. (*Blast Furn. Steel Plant*, 1955, **43**, Apr., 405–407). The development of materials for use at elevated temperatures is discussed, particular attention being paid to their use in the steam- and gas-turbine field.—B. G. B.

Are Plastics and Metals Competitors ? K. Mienes. (*Stahl u. Eisen*, 1955, **75**, Mar. 24, 317–322). A survey of modern plastics and their uses: the consumption of plastics is at present about 1% of that of ferrous metals.—T. G.

Worries and Wants of a User of Rolled Steel. E. Kemma. (*Stahl u. Eisen*, 1955, **75**, Feb. 24, 193–196). The author compares German prices and specifications of rolled-steel products with those in the U.S.A. from the point of view of the user and draws certain conclusions with regard to the relation of production, consumption, and stock keeping.—T. G.

Progress in Stainless and Heat Resisting Materials. J. Lomas. (*Eng. Boiler House Rev.*, 1954, **69**, Nov., 343–344).

The Use of Special Steels in Waterfall Harnessing Equipment. (*Aciers Fins Spéc. Franç.*, 1954, Dec., 105–109). The use of special steels to combat corrosion and erosion in water turbines is discussed, and a few details are given of the stainless and alloy steels now being used in the construction of turbine wheels and other parts.—E. A. C.

The Use of Special Steels for Railways. (*Aciers Fins Spéc. Franç.*, 1954, Dec., 29–32). The modernization programme carried out by the S.N.C.F. during the last few years has brought about a substantial increase in the use of special steels for railway equipment, and in this article numerous examples are given of their application in the construction of locomotives and coaches.—E. A. C.

Developments in Metals. (*Product Eng.*, 1955, **26**, Jan., 136–143). The development of new materials has opened up new possibilities for design. With this in mind this paper briefly outlines some of the possibilities for titanium, mixtures of metals and ceramics, metal oxides, and powder-metallurgy techniques.—A. M. F.

Bolts and Nuts: Principles of Manufacture. K. Schimz. (*Draht, German ed.*, 1955, **6**, May, 186–189). This is a brief survey of the size and composition of the West German nut and bolt industry, of methods of manufacture, compositions and properties of steels used, tools, heat-treatment, and testing and inspection.—J. G. W.

Some Factors Affecting Spring Design. W. R. Berry. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 80–92). [This issue].

When Metal Weds Plastic A New Material is Born. S. W. Baker. (*Steel*, 1954, **135**, Dec. 6, 116–119). The new material is metal sheet, bonded on one or both sides to vinyl plastic laminate. The properties, production position, and present and potential uses are considered. The sheet can be worked by most metalworking processes.—D. L. C. P.

Cermets. Materials for High-Temperature Service. R. Steinitz. (*Machine Design*, 1954, **26**, Nov., 221–224). During the last decade, new high-temperature materials called ' cermets ' have been developed, consisting of combinations of metals with refractory compounds, to help fill the gap between the so-called super alloys and ceramics.—M. A. K.

HISTORICAL

America's Industrial Beginnings Commemorated in Restoration at Saugus, Massachusetts. (*Amer. Soc. Test. Mat. Bull.*, 1955, Feb., 25–26). A short account is given of the restoration of one of the original ironworks in America.—B. G. B.

An Industry Grows. A Short History of E.S.C. (3). (*E.S.C. News*, 1955, **8**, Spring, 3–11). An account is given, against the industrial background of that period, of the development of Vickers, Sons and Maxim, Sir W. G. Armstrong-Whitworth and Co., and Cammell Laird and Co., Ltd., during the 30 years before their amalgamation as the English Steel Corporation.

Stove Plates from the Mosel Region. E. Engelhard. (*Giesserei*, 1955, **42**, Mar. 17, 128–131). A historical paper describing oven plates in private and other collections from 1500 to 1839.—R. J. W.

Technical Problems of the 17th Century. B. Gille. (*Techn. Civil.*, 1954, **3**, (6), 177–208). Scientific thought and technical progress in the 17th century are examined. Smelting with coke originated at this time.—T. E. D.

Iron. R. Dürrer. (*Roll'schen Eisenwerke Werkzeit.*, 1954, **25**, Nov., 155–159). A brief history of iron and steel making in Switzerland is given.—U. E.

The Structural Iron of the Parthenon. C. J. Livadefs. (*J. Iron Steel Inst.*, 1956, **182**, Jan., 49–66). [This issue].

ECONOMICS AND STATISTICS

The Australian Iron and Steel Industry. (*Metal Bull.*, 1955, June 28, Supplement, I–VIII). The present position in the industry is reviewed and details of its expansion programme, the deposits of raw materials, production data, and trade are given. When the development projects now in hand are complete it will have a capacity of 2,600,000 tons.—B. G. B.

The Australian Iron and Steel Industry's Post-War Expansion. N. R. Wills. (*B.H.P. Rev.*, 1954, **32**, Dec., 10–18). The post-war development of the iron and steel industry in Australia is reviewed, with particular reference to the Port Kembla works of B.H.P. The part played by the immigration programme in providing a high proportion of the necessary manpower is emphasized. Present plans include the installation of a wide steel-strip mill, as part of a project for manufacturing tinplate for the home market.—L. D. H.

The Development of the Czechoslovak Metallurgical Industry in the Period 1945–1955. (*Hutník*, (*Prague*), 1955, **5**, (5), 130–146). [In Czech].

The Manufacture of Iron and Steel in Asia and the Far East. V. M. Subramanian. (*Blast Furn. Steel Plant*, 1955, **43**, May, 517–518, 527–528).

Iron and Steel Industry in Yugoslavia. C. Rekar. (*Iron Coal Trades Rev.*, 1955, **170**, Mar. 4, 499–501).

Indian Steel Industry Expansion: British, German, and Russian Interests. (*Iron Coal Trades Rev.*, 1955, **170**, Mar. 25, 675–676). Brief details are given of the proposed expansion of the Indian steel industry, and of plant to be supplied by British, German, and Russian concerns.—G. F.

Iron and Steel Industries of Western Germany: Recent Progress. (*Iron Coal Trades Rev.*, 1955, **170**, Mar. 25, 683–684).

Iron and Steel Industry in the Pacific Basin. G. P. Contractor. (*Iron Coal Trades Rev.*, 1955, **170**, May 13, 1099–1105; May 20, 1145–1152). The author surveys current developments in the iron and steel industries of Japan, China, Formosa, Hong Kong, Korea, Malaya, Indochina, Indonesia, the Philippines, Australia, New Zealand, Mexico, Chile, Colombia, Peru, Russia, U.S.A., and Canada.—G. F.

Indian Iron and Steel Industry Expansion. (*Found. Trade J.*, 1955, **98**, Apr. 14, 409–410). Recent proposals aimed at increasing Indian steel production to six million tons per annum are briefly reviewed.—B. C. W.

MISCELLANEOUS

The Surface Areas of Evaporated Metal Films. B. M. W. Trapnell. (*Trans. Faraday Soc.*, 1955, **51**, Mar., 368–370). Surface areas versus unit weight of six metal films (including iron), prepared in two different ways, have been measured.

New Oilgasification Process. K. Guthmann. (*Stahl u. Eisen*, 1955, **75**, July 28, 985–989). The author reviews the various processes used in the gasification of oil and describes in detail that of the Office Central Chauffe Rationelle Paris.—T. G.

Physiology in Iron and Steel Works. H. Spitzer. (*Stahl u. Eisen*, 1955, **75**, June 30, 851–856).

Re-Opening of the Section " Iron and Steel " in the Deutsche Museum in Munich. H. Dickmann. (*Stahl u. Eisen*, 1955, **75**, May 5, 590–591).

Physiological Fatigue in Industry; Its Assessment, Its Alleviation. L. Brouha. (*Usine Nouvelle*, Special No., Spring, 1955, 229–239). Physical and nervous fatigue are discussed, and their physiological measurement is described. Avoidance of manual exertion and improved conditions of temperature are mentioned.—T. E. D.

The Effect of Silicon on the Thermo-Dynamic Behaviour of the Carbon in Solution in Liquid and Solid Iron. A. M. Ssamarin and L. A. Schwarzman. (*Met. u. Giesserei Techn.*, 1951, **1**, Nov., 347–348; *J. Acad. Sci.*, Moscow, 1950, (11), 1696–1700). An approximate description of the effect of Si on the action of the carbon dissolved in γ-iron can be given on the assumption that a C atom and a Si atom cannot be simultaneously contained in the elementary cell. In liquid Fe–C–Si melts,

saturated with C at 1300° C, the sum of C and Si atoms is almost constant, near 0·2. This fact can be explained by the assumption of similarity between liquid and solid solutions of carbon in iron.—L. J. L.

The First Kowaljow Analysis in Metallurgy. M. Friedemann. (*Met. u. Giesserei Techn.*, 1951, **1**, Aug., 216–228). The methods used in the textiles industry by Kowaljow for the analysis of production processes have been applied to the steel industry. Production processes and physiological problems were investigated.—L. J. L.

Chemistry and Extractive Metallurgy. H. Hohn. (*Berg. Hüttenmänn. Monatsh.*, 1955, **100**, Jan., 27–44). A comprehensive survey is presented of recent developments in chemical methods of ore treatment which make increasingly important intrusions into the field of extractive metallurgy.—E. C.

The Determination of the Size Distribution of Spheres in the Solid Body from the Circular Segment of a Plane Section. H. D. Dietze. (*Tech. Mitt. Krupp*, 1955, **13**, July, 51–55). An expression is derived showing the general relationship between the size distribution of spherical particles in a solid body and the circular segments originating from a plane section.—L. D. H.

Air For Precision Measurement. C. W. Gardner. (*Steel Processing*, 1955, **41**, Mar., 172–176). The basic principles of air gauge measurement are briefly outlined and air-jet characteristics are discussed. Multiple-jet circuits are also dealt with and various applications are described.—P. M. C.

The Rare-Earth Metals and their Present-Day Applications to Metallurgy. H. Evans. (*J. Birm. Met. Soc.*, 1954, **34**, Dec., 131–149). The chemistry, occurrence, and extraction of the rare-earth metals are briefly reviewed, and improvements in various properties of some non-ferrous alloys containing rare-earth additions are discussed. In the ferrous field, the important role played by rare-earths in the production of high-strength spheroidal cast irons is dealt with, and improved forgeability of austenitic steels and mechanical properties of some ferritic steels are discussed.—P. M. C.

Metallurgical Research in the Electrical Industry. I. Jenkins. (*J. Birm. Met. Soc.*, 1955, **35**, Mar., 151–168). A general review is presented of metallurgical studies of importance to the electrical industry. Impurities in metals, grain growth and crystal stability, and gas–metal systems are the main topics. The effects of various impurities on the corrosion and high-temperature properties of steels for steam and gas turbines and on the magnetic properties of steels for transformer equipment are discussed.—P. M. C.

Rare Earth Series—Their Atomic Structure, History and Uses. M. C. Irani. (*Queensland Gov. Min. J.*, 1955, **56**, Mar., 170–180).

The Interactions of Applied Science and Technology for the Civilian Economy and for National Security. M. J. Kelly. (*Yearbook Amer. Iron Steel Inst.*, 1954, 15–35). The author reviews recent contributions of applied science and technology to both the civilian economy and to national security, and shows how advancements in both fields are often inter-related. Future trends in the use of atomic power are suggested.—G. F.

The Control of Silicosis in the Iron and Steel Industry. H. Rosemann. (*Giessereitechnik*, 1955, **1**, Mar., 28–29). Measures to prevent silicosis include the use of quartz-free materials, dust suppression, breathing apparatus, medical examinations, and supervision of staff.—L. J. L.

Application of Photo-electricity in the Metal Industry. H. D. Schultz-Methke. (*Metall*, 1955, **9**, Feb., 97–99; Apr., 288–291). Properties of photocells are explained and their use in measuring surface colour and lustre of metallic objects discussed. The Lange colorimeter and the Beckman spectro-photometer are described. Finally, photo-electric switching installations are referred to.—J. G. W.

The Use of Free Energy Maps in Extractive Metallurgy. S. N. Anant Narayan. (*Trans. Indian Inst. Met.*, 1953, **7**, 105–122; *Tisco*, 1955, **2**, Apr., 46–51). The author introduces the principles involved in free-energy maps and describes the method of representation. The application of the charts to metallurgical processes is discussed and typical examples are given.—L. E. W.

A Survey of Metallurgical Films. J. P. Moore. (*Metallurgia*, 1955, **51**, June, 267–272).

Unit Weights of Metals. G. Sorkin and W. H. Hawley, jun. (*Machine Design*, 1955, **27**, Mar., 205–207). A tabulation for more than 240 types of ferrous and non-ferrous metals.

Radioisotopes as Design Tools. A. M. Smith. (*Product Eng.*, 1955, **26**, May, 129–135).

BOOK NOTICES

GELEJI, ALEXANDER. "*Die Berechnung der Kräfte und des Arbeitsbedarfs bei der Formgebung im bildsamen Zustande der Metalle.*" Second, revised and enlarged edition. La. 8vo, pp. 415. Illustrated. Budapest, 1955: Verlag der Ungarischen Akademie der Wissenschaften.

This book on the calculation of the forces and power requirements in the plastic deformation of metals covers a remarkably wide range of metal-working processes: press and hammer plain-tool and die forging; rolling of sheet, strip, flats, and sections; tube-making processes, including rotary and punch piercing, hot and cold pilgering, plug rolling and drawing; bar and wire drawing; turks-head drawing; deep-drawing; and the bending of bars and sheet. It is intended as a manual for plant designers, the rational treatment springing from sound theoretical foundations designed to supplant present rule-of-thumb methods of design. This worthy aim is not fully achieved, for the simple reason that there are still many gaps in metal-working science. The author is, however, to be commended not only for his courageous initial attempt but also for the effort put into frequent revisions and additions to his original text in an attempt to keep up with the rapid progress in this field. That many of the formulæ presented in the book fall short of the ideal need not deter the designer from using them, because he can make judicious adjustments by reference to the numerous experimental data quoted for comparison with the theories. Moreover, in problems not fully covered in the book recourse can be had to a large bibliography.

The mathematics is simple, and there are many worked examples. The drawbacks of the book are, first, a weak and out-of-date treatment of fundamental plasticity theory in the opening chapter, and, secondly, a notation and method of derivation of formulæ which differ from those adopted by other authorities in this field. For this reason the book is not to be recommended as a first textbook in metal-working theory; but those already conversant with the elements of the subject will find Professor Geleji's book useful for the study of processes not adequately treated elsewhere, notably tube-making and drop forging.

J. G. WISTREICH.

MONDOLFO, L. F., and OTTO ZMESKAL. "*Engineering Metallurgy.*" 8vo, pp. ix + 397. Illustrated. New York, Toronto, London, 1955: McGraw-Hill Book Company, Inc. (Price $7.50, 56*s.* 6*d.*).

It is virtually impossible to write a textbook of engineering metallurgy which will please everybody concerned with the subject. However, there is no doubt that the volume under review represents a useful effort to present the general principles of the structure and properties of metals, rather than 'potted' data, and to give an introduction to the practical aspects of fabrication and treatment, as well as dealing with the basic metallurgical principles of these operations.

The following remarks are not intended to cover the book, chapter by chapter, but merely to comment on certain features. Although the first chapter on extractive metallurgy is only intended as a brief introduction, its necessarily superficial nature raises doubt as to whether it was worth inclusion. There is a fair amount in the book on atomic matters, but the reviewer feels that, for the field covered, the treatment is possibly somewhat too terse. It should be noted here that the continuous $N(E)$ curve, Fig. 4–1 (*a*) (p. 91) is incorrectly described as representing the energy levels for the valency electrons in an atom, whereas, in fact, it refers to the possible distribution of electrons in an empty box. On the other hand, it is pleasing to note that the authors consider that there are no short-cuts to equilibrium diagrams, and accordingly the relevant chapter is relatively thorough. Corrosion and protection receive

attention, but, surprisingly, the deterioration of metals under various conditions of stressing is not covered. The latter subject is one for which the metallurgist's presentation is very desirable.

In all, the book can be recommended as lucid reading matter, suitable, for example, for degree students. For more practical students the reviewer thinks that books written in a more down-to-earth and specific manner are better suited. The volume is well illustrated and attractively, but rather expensively, produced.—A. R. BAILEY.

NEW PUBLICATIONS

AMERICAN SOCIETY FOR METALS. "*Impurities and Imperfections.*" A seminar on impurities and imperfections held during the Thirty-Sixth National Metal Congress and Exposition, Chicago, October 30 to November 5, 1954, sponsored by the American Society for Metals. 8vo, pp. [5+] 231. Illustrated. Cleveland, Ohio, 1955: The Society. (Price 50*s.* 3*d.*).

AREND, HEINRICH, and WERNER NEUHAUS. "*Die Härtbarkeit des Stahles.*" 8vo, pp. 260. Illustrated. Essen, 1955: Verlag W. Girardet. (Price DM. 28.80).

ASSOCIAÇÃO BRASILIERA DE METAIS. "*Vocabulario técnico de termos empregados em usinas siderurgicas (Inglês–Português).*" Contribuição da Companhia Siderurgica Nacional apresentada ao 1°. Congresso Anual da A.B.M. maio de 1945. La. 8vo, pp. 227–236, 169–176, 120–126, 189–200, 227–234 [reprinted from *Bol. Assoc. Brasil. Metais*]. São Paulo, [1955]: The Association.

BELCHER, R., and C. L. WILSON. "*New Methods in Analytical Chemistry.*" Pp. xii + 287. London, 1955: Chapman & Hall, Ltd. (Price 30*s.*).

BRAME, J. S. S., and J. G. KING. "*Fuel: Solid, Liquid and Gaseous.*" Fifth edition, rewritten by Dr. J. G. King. 8vo, pp. xii + 551. Illustrated. London, 1954: Edward Arnold (Publishers), Ltd. (Price 50*s.*).

BRITISH ELECTRICAL AND ALLIED MANUFACTURERS' ASSOCIATION. "*BEAMA Guide to British Arc Welding Electrodes.*" (BEAMA Publication No. 144, 1955.) 8vo, pp. iv + 68. Illustrated. London, 1955: The Association. (Price 5*s.*).

BRITISH IRON AND STEEL RESEARCH ASSOCIATION. "*Specification for Heavy Duty Electric Overhead Travelling Cranes for Use in Iron and Steel Works.*" Prepared by the Steelworks Cranes Sub-Committee of the Plant Engineering Division. La. 4to, pp. [v +] 33. Illustrated. London, 1955: The Association. (Free to members of BISRA; price 10*s.* to non-members).

BRITISH STANDARDS INSTITUTION B.S. 2630 : 1955. "*Projection Welding of Low Carbon Steel Sheet and Strip.*" 8vo, pp. 11. Illustrated. London, 1955: The Institution. (Price 2*s.* 6*d.*).

CHAMBRE SYNDICALE TRAMAGRAS. "*Premier Congrès Mondial de la Détergence et des Produits Tensio-Actifs.*" [Report on the Proceedings of the Congress held in the Sorbonne, Paris, from 30th August to 3rd September, 1954.] La. 4to, illustrated. Section 1, "*Physico-Chimie des Produits Tensio-Actifs,*" pp. 151. Section 2, "*Analyse et Identification des Produits Tensio-Actifs,*" pp. 67. Section 3, "*Méthodes d'Essais des Produits Tensio-Actifs,*" pp. 87. Section 11, "*Industrie Mechanique—Métallurgie,*" pp. 35. Paris, [1955]: Chambre Syndicale Tramagras. (Prices: Section 1, 440 fr.; Sections 2 and 3, 400 fr. each; Section 11, 280 fr.).

COMITÉ INTERNATIONAL DES ASSOCIATIONS TECHNIQUES DE FONDERIE. "*Dictionnaire de Fonderie.*" Edition provisoire [limité au chapitre "Fusion"]. Rédigé par le Comité International du Dictionnaire Technique de Fonderie. La. 8vo, pp. xxiv + 93. Milan, 1955: Comité International du Dictionnaire Technique de Fonderie. (Price 5*s.*).

COMMISSION INTERNATIONALE DES DÉFAUTS DE FONDERIE. "*Album des Défauts de Fonderie.*" II. "*Acier Moulé, Fonte Malleable, Alliages de Cuivre, d'Aluminium, de Magnésium.*" La. 8vo, pp. iii + 225. Illustrated. Paris, 1955: Editions Techniques des Industries de la Fonderie. (Price 2500 fr.).

CRAWFORD, ALAN E. "*Ultrasonic Engineering, with Particular Reference to High Power Applications.*" 8vo, pp. x + 344. Illustrated. London, 1955: Butterworths Scientific Publications. (Price 45*s.*).

FUCHS, W. "*Studien über die thermische Zersetzung der Kohle und die Kohlendestillationsprodukte.*" (Forschungsberichte des Wirtschafts- u. Verkehrsministeriums Nordrhein-Westfalen, Nr. 139). Pp. 48. Illustrated. Berlin, Opladen, 1955: Westdeutscher Verlag. (Price DM. 11.80).

GARNER, W. E. (Editor). "*Chemistry of the Solid State.*" La. 8vo, pp. viii + 417. Illustrated. London, 1955: Butterworths Scientific Publications. (Price 50*s.*).

GROSSKINSKY, OTTO. "*Handbuch des Kokereiwesens.*" Unter Mitarb. von C. Abramski u.a. Vol. 1. 8vo, pp. xvi + 547. Illustrated. Düsseldorf, 1955: K. Knapp. (Price DM. 76.–).

GROUPEMENT POUR L'AVANCEMENT DES MÉTHODES D'ANALYSE SPECTROGRAPHIQUE DES PRODUITS MÉTALLURGIQUES. "*Dix-septième Congrès tenu les 23, 24 et 25 Juin 1954 à Paris.*" La. 8vo, pp. 479. Illustrated. Arcueil (Seine), France [1955]: G.A.M.S.

IRON AND STEEL INSTITUTE. "*Developments at the Consett Works of the Consett Iron Company Limited.*" (Iron and Steel Institute Special Report No. 54). La. 4to, pp. [vi +] 48. Illustrated. London, 1955: The Institute. (Price 25*s.*; members 15*s.*).

LEROY, A., M. ERRARD, and G. D'HERBEMONT. "*La Pratique du Soudage Oxyacétylènique et des Techniques Connexes.*" 8vo, pp. 344. Illustrated. Paris, 1955: Soudure Autogène. (Price 600 fr.).

LI, K. C., and CHUNG YU WANG. "*Tungsten.*" Its History, Geology, Ore-Dressing, Metallurgy, Chemistry, Analysis, Applications and Economics. (American Chemical Society Monograph No. 94). Third edition. 8vo, pp. xx + 506. Illustrated. New York, 1955: Reinhold Publishing Corporation; London: Chapman & Hall, Ltd. (Price 112*s.*).

LOW, BEVIS BRUNEL. "*Strength of Materials.*" Second edition: 8vo, pp. vii + 320. Illustrated. London, 1955: Longmans, Green & Co., Ltd. (Price 18*s.* 6*d.*).

NATIONAL BUREAU OF STANDARDS. "*Reference Tables for Thermocouples.*" (N.B.S. Circular No. 561). Pp. 84. Washington, D.C., 1955: Government Printing Office. (Price 25 cents).

"*The Papers of William Froude, M.A., LL.D., F.R.S., 1810–1879.*" With a Memoir by Sir Westcott Abell, K.B.E., M.Eng., and an Evaluation of William Froude's Work by R. W. L. Gawn, C.B.E., D.Sc., R.C.N.C. Collected into One Volume by The Institution of Naval Architects and prepared for publication by the Secretary of the Institution, Captain A. D. Duckworth, R.N. La. 4to, pp. xxii + 344. Illustrated. London, 1955: The Institution of Naval Architects.

SOUTH AUSTRALIA DEPARTMENT OF MINES. "*The Geology and Iron Ore Resources of the Middleback Range Area.*" Geological Survey of South Australia, Bulletin No. 33. By Keith R. Miles. La. 8vo, pp. 247. Illustrated. Adelaide, 1955: Geological Survey Office.

STETANOFF, A. J. "*Turboblowers.*" La. 8vo, pp. 377. Illustrated. New York, 1955: John Wiley and Sons, Inc. (Price $8.00).

TORE, NORÉN. "*Werkstoffkunde für die Lichtbogen-Schweissung von Eisen und Stahl.*" (Übersetz. aus dem Schwed.) 8vo, pp. 218. Illustrated. Solingen, 1955: Kjellberg Esab G.m.b.H. (Price DM. 9.80).

TRINKS, W. "*Industrial Furnaces.*" Volume II, third edition. La. 8vo, pp. 358. Illustrated. New York, 1955: John Wiley and Sons, Inc.; London: Chapman & Hall, Ltd. (Price $10.00).

T. H. ARNOLD, F.I.M.

THOMAS H. ARNOLD received his early education at the Cockburn High School, Leeds, and entered the chemical laboratories of the Leeds Steel Works as a trainee in 1905. After a period in the analytical laboratory his duties were extended to cover technical services to the various production departments, which embraced blast-furnaces, Bessemer converters, and rolling mills, and he was put in charge of a newly created metallographic laboratory. During this time he was furthering his education by evening studies at the Leeds Modern School and Leeds University.

In 1915 he joined the staff of the chemical laboratory of Hadfields Ltd., and in 1920 he was placed in charge of the metallographic and corrosion laboratories, where he was closely associated with many of the researches of the late Sir Robert Hadfield. In 1947 he was appointed to his present position of Deputy Controller of Research.

He has been an active member of the Sheffield Metallurgical Association since joining in 1923, having been respectively Member of Council, Librarian, and Treasurer, and is the President for the Session 1954-1955. He is a Fellow of the Institution of Metallurgists.

Mr. Arnold served as an Honorary Member of the Council of The Iron and Steel Institute during his term as President of the Sheffield Metallurgical Association.

T. H. Arnold, F.I.M.

Honorary Member of Council, 1954-1955